A tool for Human Factors Accident Investigation, Classification and Risk Management

Keith C. Hendy

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Author

Keith C. Hendy

Approved by

Keith C. Hendy

Head, Human Factors Research and Engineering Section

Approved for release by

Kathy M. Sutton

Head, Document Review and Library Committee

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Abstract

A tool for Systematic Error and Risk Analysis (SERA), based on a solid theoretical framework provided by the Information Processing (IP) and Perceptual Control Theory (PCT) models, has been developed for investigating the human factors causes of accidents and incidents. SERA provides a structured process for identifying both active failures and the pre-conditions that led to these failures. In the context of this report, SERA is developed as a tool to help the accident investigator in populating the Canadian Forces version of the Human Factors Accident Classification System or HFACS. Yet SERA provides its own taxonomy of human factors causes and could stand alone, independent of HFACS, as both an investigation tool and as an accident classification taxonomy. Because of the strong separation between the active failures and pre-conditions that mark the points of intervention for the safety system, SERA can be extended to provide a risk management tool at both the tactical (for operators) and strategic (for managers) levels. A concept for a risk management tool is developed, based on 12 SERA factors at the tactical level and six SERA factors at the strategic level. The use of a software tool for implementing the steps of the SERA analysis is demonstrated.

Résumé

Un outil d'analyse systématique des erreurs et du risque (SERA) a été développé pour enquêter sur les facteurs humains en cause dans les accidents et les incidents. Il est fondé sur un cadre théorique solide élaboré à partir du modèle de traitement de l'information (TI) et de celui des principes du contrôle perceptif (PCP). La SERA offre un processus structuré permettant d'identifier à la fois les défaillances actives et les préconditions ayant mené à ces défaillances. Dans le contexte de ce rapport, la SERA a été développée en tant qu'outil pour aider les enquêteurs sur les accidents à charger le système d'analyse et de classification des facteurs humains (SACFH) propre aux Forces canadiennes. Pourtant, la SERA a sa propre taxonomie des causes de facteurs humains et pourrait opérer par elle-même, indépendamment du SACFH, comme un outil d'enquête et comme une taxonomie de classification des accidents. Vu le grand écart entre les défaillances actives et les préconditions amenant des interventions du système de secours, la SERA peut aussi servir d'outil de gestion du risque aux niveaux tactique (pour les utilisateurs) et stratégique (pour les gestionnaires). Un concept d'outil de gestion du risque est développé selon 12 facteurs SERA au niveau tactique, et selon 6 facteurs SERA au niveau stratégique. L'utilisation d'un outil logiciel pour mettre en oeuvre les étapes de la SERA est expliquée.

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Executive summary

As technology has become increasingly reliable, accidents due to equipment and material failure have become rare. Now days, cause factors are more likely to be attributed to the human elements in the system than to the hardware. Obviously the ability to investigate, classify and track human factors causes of accident and incidents is central to preventing their recurrence or for putting in place traps to stop these 'human errors' from propagating. A tool for human factors accident investigation and classification must provide insight into why a particular pattern of behaviour was observed. Generally one is concerned with the behaviour that led directly to the accident or incident. Understanding why this pattern of behaviour emerged is the key to explaining the human factors issues associated with the occurrence. The Systematic Error and Risk Assessment (SERA) process sets out to do this

SERA is based on a solid theoretical framework provided by the Information Processing (IP) and Perceptual Control Theory (PCT) models. SERA provides a structured process for identifying both active failures and the pre-conditions that led to these failures. In the context of this report, SERA is developed as a tool to help the accident investigator in populating the Canadian Forces version of the Human Factors Accident Classification System or HFACS.

Yet SERA provides its own taxonomy of human factors causes and could stand alone, independent of HFACS, as both an investigation tool and as an accident classification taxonomy. Because of the strong separation between the active failures and pre-conditions that mark the points of intervention for the safety system, SERA can be extended to provide a risk management tool at both the tactical (for operators) and strategic (for managers) levels. A concept for a risk management tool is developed, based on 12 SERA factors at the tactical level and six SERA factors at the strategic level.

SERA gains construct and face validity from the theoretical models on which it is based, but lacks the appeal of a tool that seen widespread field use such as HFACS. SERA has a formal process for its application that suggests a greater level of complexity than HFACS. This suggestion of complexity is perhaps more imagined than real as the SERA decision ladders are simple to navigate, although they do demand that the investigator is able to answer a series of questions related to the operator's goals, state of knowledge of the world, and their planned actions. While this might seem odious, it is hard to imagine that an understanding of the circumstances of the accident or incident can be obtained in the absence of this information. A software tool that simplifies the process of conducting a SERA analysis is demonstrated.

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Sommaire

Étant donné que la technologie est de plus en plus fiable, les accidents dus aux défaillances de l'équipement et du matériel sont de plus en plus rares. De nos jours, les causes sont plus souvent qu'autrement attribuées aux éléments humains du système qu'au matériel. Il va de soi que l'enquête, la classification et le suivi des facteurs humains en cause lors d'accidents sont essentiels à la prévention de leurs récurrences et à la pose de pièges pour empêcher la propagation de ces « erreurs humaines ». Un outil d'enquête et de classification des accidents dus aux facteurs humains doit pouvoir expliquer pourquoi un type de comportement particulier a été observé. Habituellement, on s'intéresse au comportement ayant directement mené à l'accident ou à l'incident. Comprendre pourquoi ce type de comportement est survenu est la clé pour expliquer les facteurs humains associés avec cet événement. Tel est le r du processus d'analyse systématique des erreurs et du risque (SERA).

La SERA se fonde sur un cadre théorique solide élaboré à partir du modèle de traitement de l'information (TI) et de celui des principes du contrôle perceptif (PCP). Elle offre un processus structuré permettant d'identifier à la fois les défaillances actives et les préconditions ayant mené à ces défaillances. Dans le contexte de ce rapport, la SERA a été développée en tant qu'outil pour aider les enquêteurs sur les accidents à charger le système d'analyse et de classification des facteurs humains (SACFH) propre aux Forces canadiennes.

Pourtant, la SERA a sa propre taxonomie des causes de facteurs humains et pourrait opérer par elle-même, indépendamment du SACFH, comme un outil d'enquête et comme une taxonomie de classification des accidents. Vu le grand écart entre les défaillances actives et les préconditions amenant des interventions du système de sûreté, la SERA peut aussi servir d'outil de gestion du risque aux niveaux tactique (pour les utilisateurs) et stratégique (pour les gestionnaires). Un concept d'outil de gestion du risque est développé selon 12 facteurs SERA au niveau tactique, et selon 6 facteurs SERA au niveau stratégique.

La SERA gagne en validité conceptuelle et apparente sur le modèle à partir duquel il est fondé, mais il lui manque encore l'attrait de l'outil ayant été utilisé à grande échelle sur le terrain, comme le SACFH. La SERA possède un processus officiel pour son application, ce qui suggère une plus grande complexité que le SACFH. Cette complexité possible tient plus de la fiction que de la réalité, étant donné qu'il est simple de naviguer parmi les échelons de décision de la SERA; par contre, il faut que l'enquêteur puisse répondre à une série de questions sur les buts de l'utilisateur, sur l'état de ses connaissances sur le monde et sur ses actions prévues. Bien que cela puisse sembler choquant, il est difficile d'imaginer qu'une compréhension des circonstances menant à l'accident ou à l'incident soit possible en l'absence de ces informations. Un outil logiciel simplifiant le processus de la conduite d'une SERA est démontré.

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Introduction

As technology has become increasingly reliable, accidents due to equipment and material failure have become rare. Now days, cause factors are more likely to be attributed to the human elements in the system than to the hardware. Obviously the ability to investigate, classify and track human factors causes of accident and incidents is central to preventing their recurrence or for putting traps in place to stop these 'human errors' from propagating. The Human Factors Analysis and Classification System (HFACS) is one such system (Shappell and Wiegmann, 2000). HFACS draws on the influential work of Reason (1990) which recognizes not just the existence of the unsafe acts committed by the operators or crew directly involved in the accident or incident, but the presence of pathogens lying dormant in the system that make the unsafe acts more likely. Reason's *Latent Failures Model* (Figure 1) has had an enormous influence on how human error and risk management is currently viewed.

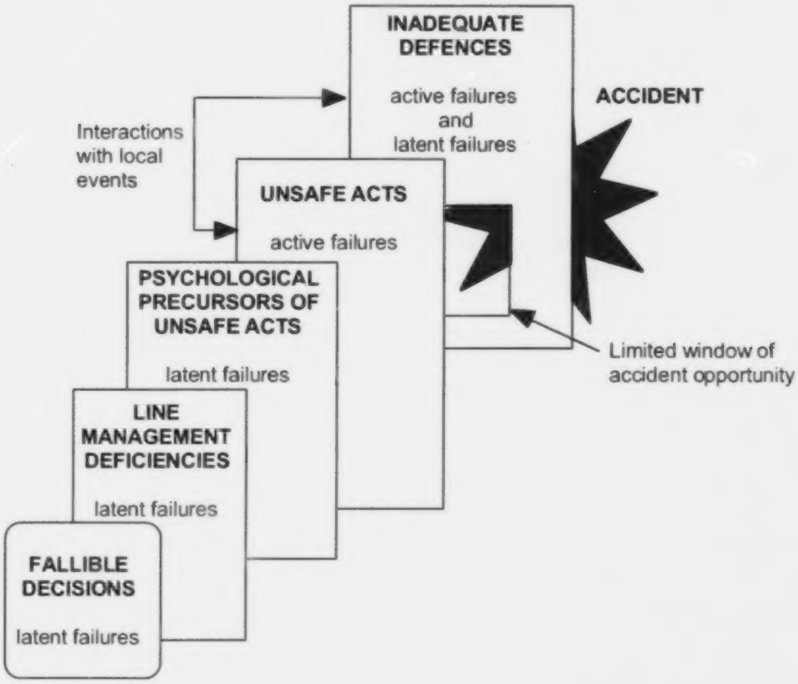
INADEQUATE DEFENCES
active failures and latent failures
ACCIDENT
Interactions with local events
UNSAFE ACTS
active failures
PSYCHOLOGICAL PRECURSORS OF UNSAFE ACTS
latent failures
Limited window of accident opportunity
LINE MANAGEMENT DEFICIENCIES
latent failures
FALLIBLE DECISIONS
latent failures

Figure 1. *James Reason's* Latent Failures Model *for accidents and incidents.*

Reason proposes three levels of latent factors that precede the active failure and pre-dispose the system to generate the unsafe act, namely:

- psychological precursors;

- line management deficiencies; and
- fallible management decisions.

In Reason's terms, when defences fail at all of these levels then these latent factors and active failures are allowed to propagate resulting in an accident or incident. Shappell and Wiegmann (2000) have re-cast Reason's latent conditions into what are largely equivalent terms, namely:

- pre-conditions for unsafe acts;
- unsafe supervision; and
- organizational influences.

Yet despite the elegance of Reason's work, and the insight it has provided for human error management, it has been argued that the *Latent Failures Model* lacks a theoretical basis for connecting cause and effect. For example, see Hendy and Lichacz (1999, p658):

> *"...It is important to note that Reason's latent failures are not outcome failures but instead are conditions that can lead to outcome failures...While these 'conditions' for human error provide valuable insights into our understanding of human error production, Reason's Latent Failure Model lacks a theoretical framework of the human information processor from which to derive predictions about why and when these latent failures will be triggered."*

Two theoretical models are advanced to address this criticism.

> *"...The Information Processing / Perceptual Control Theory model provides a framework which is consistent with the view of the human as a goal-directed, error-correcting system and provides a context from which to discuss the* why *and* when *components lacking from Reason's model, and ultimately support for a CRM or error management program."*

Together the Information Processing (IP) and Perceptual Control Theory (PCT) models provide the structure for an error and risk management system. The use of theoretical models carries with it the possibility that cause and effect might be connected through the theoretical framework in clear and unambiguous terms. Further, a theoretically driven approach is more likely to yield a complete and orthogonal classification system than what might be described as, at best, a descriptive model.

This report describes the Systematic Error and Risk Analysis process or SERA. SERA provides: a tool for investigating the human factors issues of accidents and incidents; a potential accident and incident classification taxonomy; and the basis for a risk management tool at both the tactical and strategic levels. A bridge is also developed between the SERA categories and HFACS so that the results of a SERA analysis can be recast for entry into a HFACS database.

A Theoretical Basis

The IP Model is described in detail elsewhere (Hendy, East, and Farrell, 2001b; Hendy, Liao, and Milgram, 1997). The essence of the IP model is that all factors that impact on human cognitive workload can be reduced to their effects on the amount of information to be processed and the amount of time available before the decision has to be actioned. From this position, it can be shown that if humans are limited at the rate at which they process information then operator workload, performance, and error production are all functions of the time pressure. Time Pressure is proportional to:

$$\text{Time Pressure} \propto \frac{\text{Amount of information to be processed}}{\text{Time available}}$$

which, at a constant rate of processing, reduces to,

$$\text{Time Pressure} = \frac{\text{Time to process information}}{\text{Time available}}.$$

The IP Model is about time and the information to be processed (knowledge). The IP model applies everywhere in the human cognitive system where information is being processed.

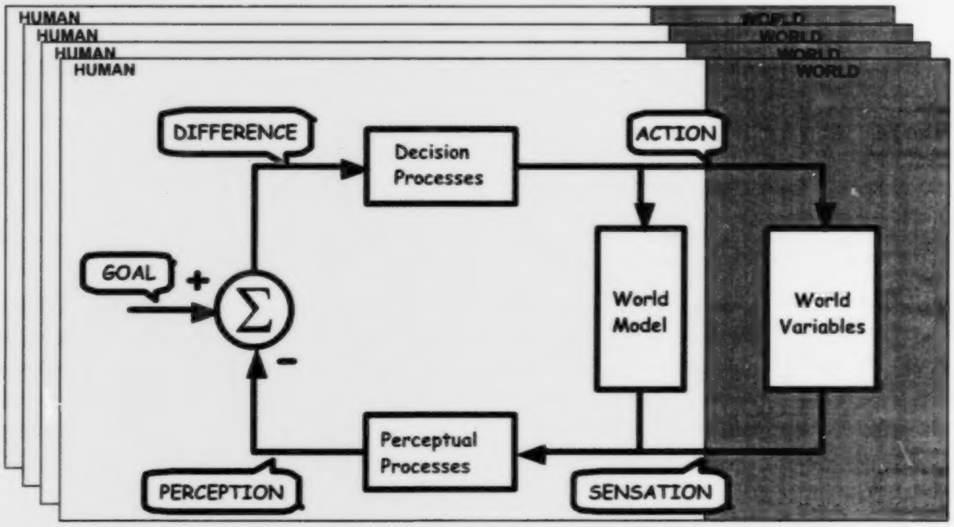
HUMAN
HUMAN
HUMAN
HUMAN
WORLD
WORLD
WORLD
WORLD
DIFFERENCE
Decision Processes
ACTION
GOAL
+
Σ
-
World Model
World Variables
Perceptual Processes
PERCEPTION
SENSATION

Figure 2. The multi-layered Perceptual Control loop for a human operator interacting with the world.

The PCT Model (Powers, 1973) argues that humans behave as multi-layered closed loop control systems (See Figure 2). The set points for these control loops are our perceptual goals (or how we want to see, hear, feel, taste, or smell the state of the world). According to PCT,

A Theoretical Basis

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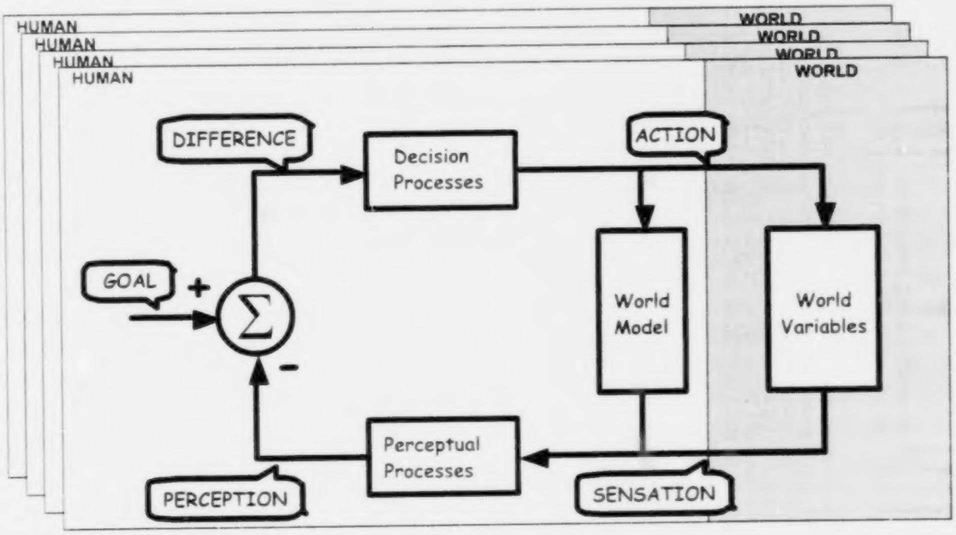
HUMAN
HUMAN
HUMAN
HUMAN
WORLD
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The IP model acts wherever there are data transformation or information processing actions. These occur in the perceptual processes, the decisional processes and in the internal world model processes. Combining the IP and PCT models it is shown that human decision-making depends on the management of time, knowledge and attentional resources (Hendy and Lichacz, 1999).

The bottom line

The principal points of the combined IP/PCT model can be summarised in the following 6 edicts:

1. Time pressure

Error production, level of performance and perceptions of workload all depend on the perceived time pressure.

2. Speed and accuracy trade-off

In human information processing — what might be colloquially called decision-making — speed and accuracy trade-off.

3. Reducing time pressure

There are two, and only two, fundamental time management strategies for reducing the perceived time pressure

- Make the decision simpler resulting in less information to process (use rules of thumb or heuristics, prioritise, delegate, postpone, schedule, pre-plan etc.).
- Extend the time before you have to respond.

4. Error management

A feedback system is error correcting…all error correcting systems use feedback.

5. Resource management

The decisions you make draw on what you know of the world (the content of all your internal knowledge structures – you may not be consciously aware of all items in your knowledge structures). To **know** you must **attend**[1], to **attend** you must have **time**. This is particularly relevant in talking about the transient or situationally specific knowledge called Situation Awareness or SA (e.g., see Endsley, 1993).

6. Ignorance is NOT bliss

What you don't know can hurt you (see edict 5 above).

---

[1] Actually this could be re-stated as "To **know** you must **control**, and to **control** you must have **time**." This applies strictly to those loops that compete for common processing structures and hence compete for processing time (see Hendy, K. C., and Farrell, P. S. 1997). This statement will generally apply to those activities that are accessible to conscious thought. It may not be true of those loops that said to be pre-attentive or those that are not available to consciousness. In IP model terms, these activities involve dedicated single purpose neural networks and therefore there is no competition for processing time.

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A Tool for Accident Investigation and Classification (SERA)

A tool for human factors accident investigation and classification must provide insight into why a particular pattern of behaviour was observed. Generally one is concerned with the behaviour that led directly to the accident or incident. Understanding why this pattern of behaviour emerged is the key to explaining the human factors issues associated with the occurrence. Using the theoretical constructs of the IP/PCT model, the Systematic Error and Risk Analysis (SERA) process sets out to do this.

IP/PCT is used to establish a consistent framework for linking cause to effect. SERA attempts to be exhaustive and establish an orthogonal set of failure descriptors from which points of intervention might be proposed. In all accident or incident investigation, the key to the process is to identify the point at which there was a departure from safe operation.

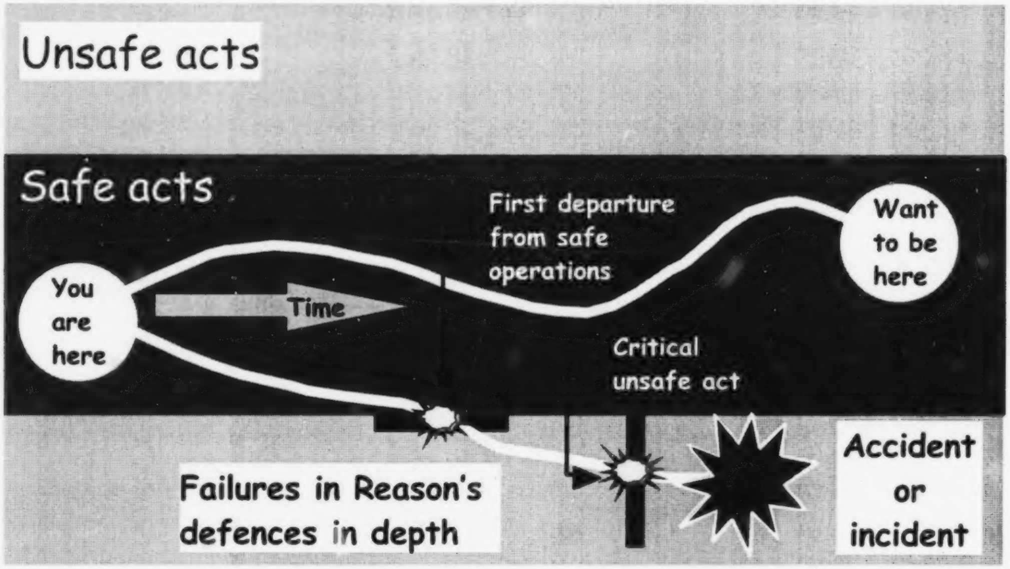
Unsafe acts
Safe acts
First departure from safe operations
Want to be here
You are here
Time
Critical unsafe act
Accident or incident
Failures in Reason's defences in depth

Figure 3. Accident and incident trajectories.

Departure from safe operation

If there has been an accident or incident there must have been a departure from safe operation at some point in the timeline (see Figure 3). Some world state must have gone outside acceptable limits (e.g., clearance from terrain, separation from another aircraft, the installation of the wrong part, the torque on a fastener). An observable unsafe act or unsafe condition will mark this point. A particular unsafe act or unsafe condition is on the accident or incident trajectory, if its removal or modification would have prevented the accident or incident from occurring. The most critical unsafe act or condition is that from which there is only one trajectory…the one that led directly to the accident or incident. Up until that critical act or condition, there are always options, but once the critical decision has been made there is no way back.

WHAT IS AN UNSAFE ACT? An act is something that someone has done…it is observable…it is the outcome of a decision (e.g., "…the pilot initiated a roll and pull-through manoeuvre from 2500ftAGL). You might have risky intentions, but until such time as you take action there is no unsafe act. Having a risky goal does not constitute an unsafe act until something is done about it, although announcing your intent to another party may be considered an unsafe act if there is an expectation that the intent will be carried out.

WHAT IS AN UNSAFE CONDITION? A condition is some state of the world. It also is observable (e.g., "…the aircraft descended below the MDA without the runway in sight"). Here you are describing, "…what was" rather than "…what was done."

WHO DO YOU START WITH? One would start with the operators or crews who were **directly** involved in the unsafe act or unsafe condition. These are the operators or crews who were controlling the variable(s) that went out of the acceptable range(s). One is trying to find out why these particular operators or crews were involved in an accident or incident. For other operators or crews, under the same pre-conditions, the outcome may have been different.

Now you need to find out what were the points of failure that led to the unsafe acts or conditions.

Why did they do that?

From PCT it is predicted that the answer to the question "…why did they do that?" is generally resolvable once you know:

- what a person's goal is;
- how they perceived the world; and
- how they were trying to achieve the goal.

Hence, if you wish to know why someone is behaving in a particular fashion you must start with the following three questions (see Figure 4).

GOAL:	What was the person trying to achieve…what was the intent?
PERCEPTION:	What did the person believe was the state of the world with respect to the goals?
ACTION:	How was the person trying to achieve the goals…what was the plan?

From the answers to these questions you can trace a causal chain from an unsafe act to the active points of failure. Within the PCT construct, active points of failure might be found in one or more of the PERCEPTUAL, GOAL setting, or ACTION selection and execution

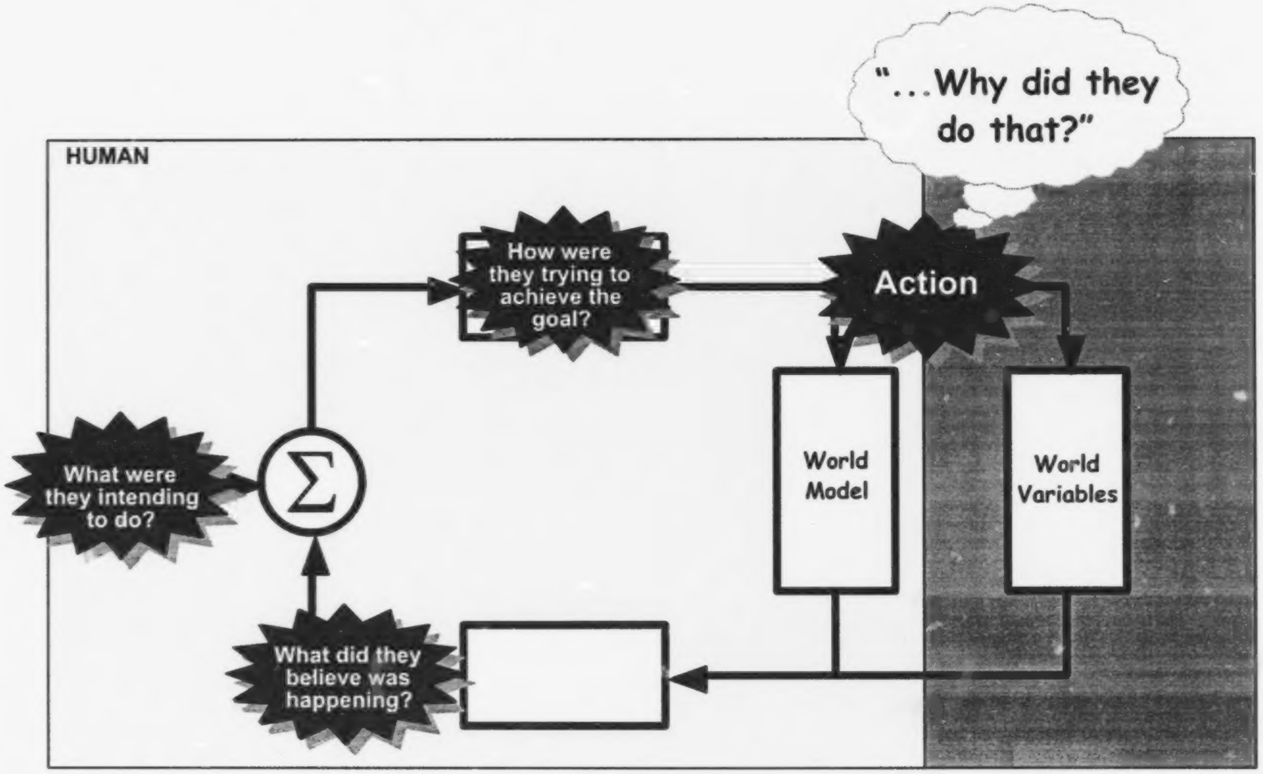
"...Why did they do that?"
HUMAN
How were they trying to achieve the goal?
Action
What were they intending to do?
Σ
World Model
World Variables
What did they believe was happening?

Figure 4. Three questions to ask.

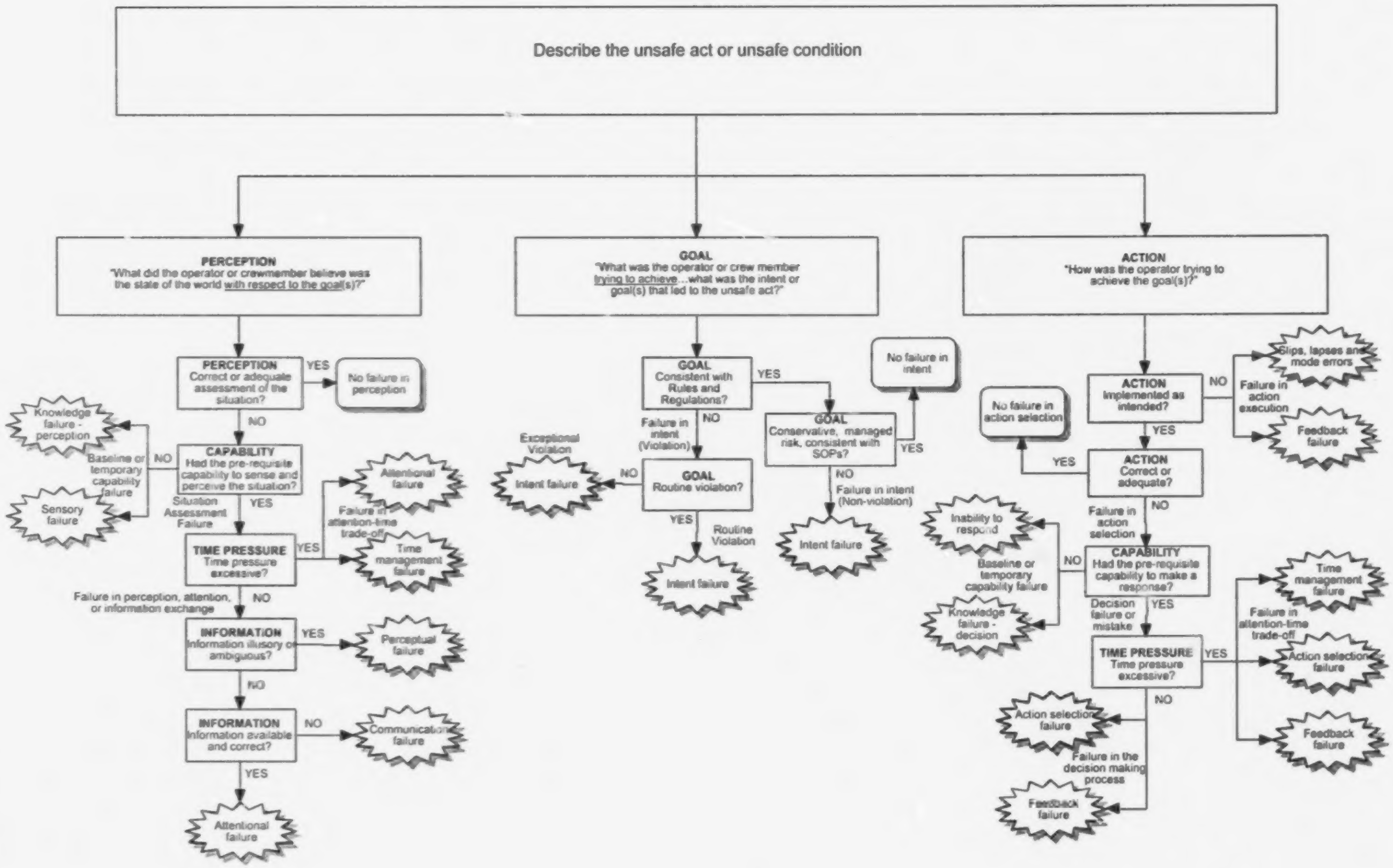
Describe the unsafe act or unsafe condition
PERCEPTION
"What did the operator or crewmember believe was the state of the world with respect to the goal(s)?"
GOAL
"What was the operator or crew member trying to achieve…what was the intent or goal(s) that led to the unsafe act?"
ACTION
"How was the operator trying to achieve the goal(s)?"
PERCEPTION
Correct or adequate assessment of the situation?
YES
No failure in perception
NO
CAPABILITY
Had the pre-requisite capability to sense and perceive the situation?
NO
Baseline or temporary capability failure
Knowledge failure - perception
Sensory failure
Situation Assessment Failure
YES
TIME PRESSURE
Time pressure excessive?
YES
Failure in attention-time trade-off
Attentional failure
Time management failure
Failure in perception, attention, or information exchange
NO
INFORMATION
Information illusory or ambiguous?
YES
Perceptual failure
NO
INFORMATION
Information available and correct?
NO
Communication failure
YES
Attentional failure
GOAL
Consistent with Rules and Regulations?
YES
GOAL
Conservative, managed risk, consistent with SOPs?
YES
No failure in intent
NO
Failure in intent (Non-violation)
Intent failure
NO
Failure in intent (Violation)
GOAL
Routine violation?
NO
Exceptional Violation
Intent failure
YES
Routine Violation
Intent failure
ACTION
Implemented as intended?
NO
Failure in action execution
Slips, lapses and mode errors
Feedback failure
YES
ACTION
Correct or adequate?
YES
No failure in action selection
NO
Failure in action selection
CAPABILITY
Had the pre-requisite capability to make a response?
NO
Baseline or temporary capability failure
Inability to respond
Knowledge failure - decision
Decision failure or mistake
YES
TIME PRESSURE
Time pressure excessive?
YES
Failure in attention-time trade-off
Time management failure
Action selection failure
Feedback failure
NO
Failure in the decision making process
Action selection failure
Feedback failure

Figure 5. PCATCT decision ladders.

processes. Time pressure, and the state of knowledge held by the operator at the time the decision was made, will bound the domain within which the active failures occur. Figure 5 traces a complete process, presented as a series of decision ladders, that starts with the answers to these three questions and finishes with twelve basic types of active failures in the human information processing system. A process for navigating these decision ladders is described in detail at Annex B to this report.

Active failures

The decision ladders of Figure 5 lead to twelve basic types of active failure, as follows.

1. Intent Failure;
2. Attention Failure;
3. Sensory Failure;
4. Knowledge (Perception) Failure;
5. Perception Failure;
6. Communication/Information Failure;
7. Time Management Failure;
8. Knowledge (Decision) Failure;
9. Ability to Respond Failure;
10. Action Selection Failure;
11. Slips, Lapses and Mode Errors;
12. Feedback Failure.

Detailed definitions of each of these active failures can be found in Annex A of this Report. Figure 6 shows the points of active failure mapped against the structure of the perceptual control loop.

Pre-conditions to active failures

Reason's *Latent Failures Model* provides two points of focus, the active failures themselves and the pre-conditions that made the active failures more likely. The explicit representation of latent or dormant pathogens in the system is perhaps the greatest contribution of Reason's work to error management.

In SERA the four levels of Reason' *Latent Failures Model* are expressed as follows (see Figure 7):

1. **Active failures**: the twelve points of breakdown in the human information processing system.
2. **Pre-conditions**: these are factors that are directly and immediately connected to the unsafe act or condition. They are defined in terms of:

    - the condition of the personnel,
    - the condition of the task (time pressure and objectives), and
    - the working conditions (equipment, workspace and environment).

   These three categories of immediate pre-conditions describe the condition of **WHO** was involved in the unsafe act, in the service of **WHAT** task, **WHY** the task is taking place, and **WHERE** (in other words, the environment, including the equipment and workspace; cf. the SHEL model of Edwards, 1988) it is performed. Time of day (**WHEN**) effects will be reflected in both the physiological condition of the personnel (e.g., circadian effects) and in the environmental conditions (e.g., ambient light levels).

3. **Organizational influences**: these are remote factors that establish the purpose of the activities to be performed, control the resources, define the climate within which the activities are to be performed, set constraints that bound behaviour though procedures, rules and regulations, and provide oversight.
4. **Command, Control and Supervision failures**: these are defined in terms of forming strategic goals, the communication of those goals, and the provision of error correcting feedback. The Command, Control and Supervisory process is the conduit whereby the organisational layer affects the immediate pre-conditions.

Figure 7 retains the basic form of HFACS (Shappell and Wiegmann, 2000) but differs in detail. Within the framework of Figure 7, the activities of the personnel can be traced back to strategic goals, shaped by organisational constraints, that flow from the Mission, down through the Command, Control and Supervisory processes, and emerge as task objectives. Figure 7 is consistent with the PCT view that all human systems are purposeful goal driven systems. Organisational influences determine the factors that constrain this purposeful goal driven system, and shape the goals that are actually serviced as distinct from those that should be pursued in the achievement of the mission objectives (of course in a healthy and effective system these will be identical).

It is intended that SERA is sufficiently complete as a classification system to capture most human factors failures and all reasonable points of intervention. While the active failure layer in SERA is directly traceable to IP/PCT, the pre-conditions shown in Figure 7 are less bounded by theory. The taxonomies investigated by Wiegmann and Shappell (1997) apply only to the active failures, which are already comprehensively covered by IP/PCT, and therefore provide no further guidance. HFACS draws obscurely on several descriptive models through its linkage with *The Taxonomy of Unsafe Operations* (Shappell and Wiegmann, 1997), but again there is no clear guidance. Although one might be guided by concepts of hierarchical systems decompositions such as Hierarchical Goal Analysis (see Hendy, Beevis, Lichacz, *et al.*, 2001), the arguments for the remaining layers in Figure 7 are constrained to be somewhat qualitative.

The immediate pre-conditions of Figure 7 include the fundamental conditions of at least three of the four factors in the SHEL model of Edwards (1988), namely:

[H]ardware – physical resources such as buildings, vehicles, equipment, and materials.

[E]nvironment – the physical and social environment (the economic and political climate will be seen at the organisational level in SERA).

[L]iveware – the human resources.

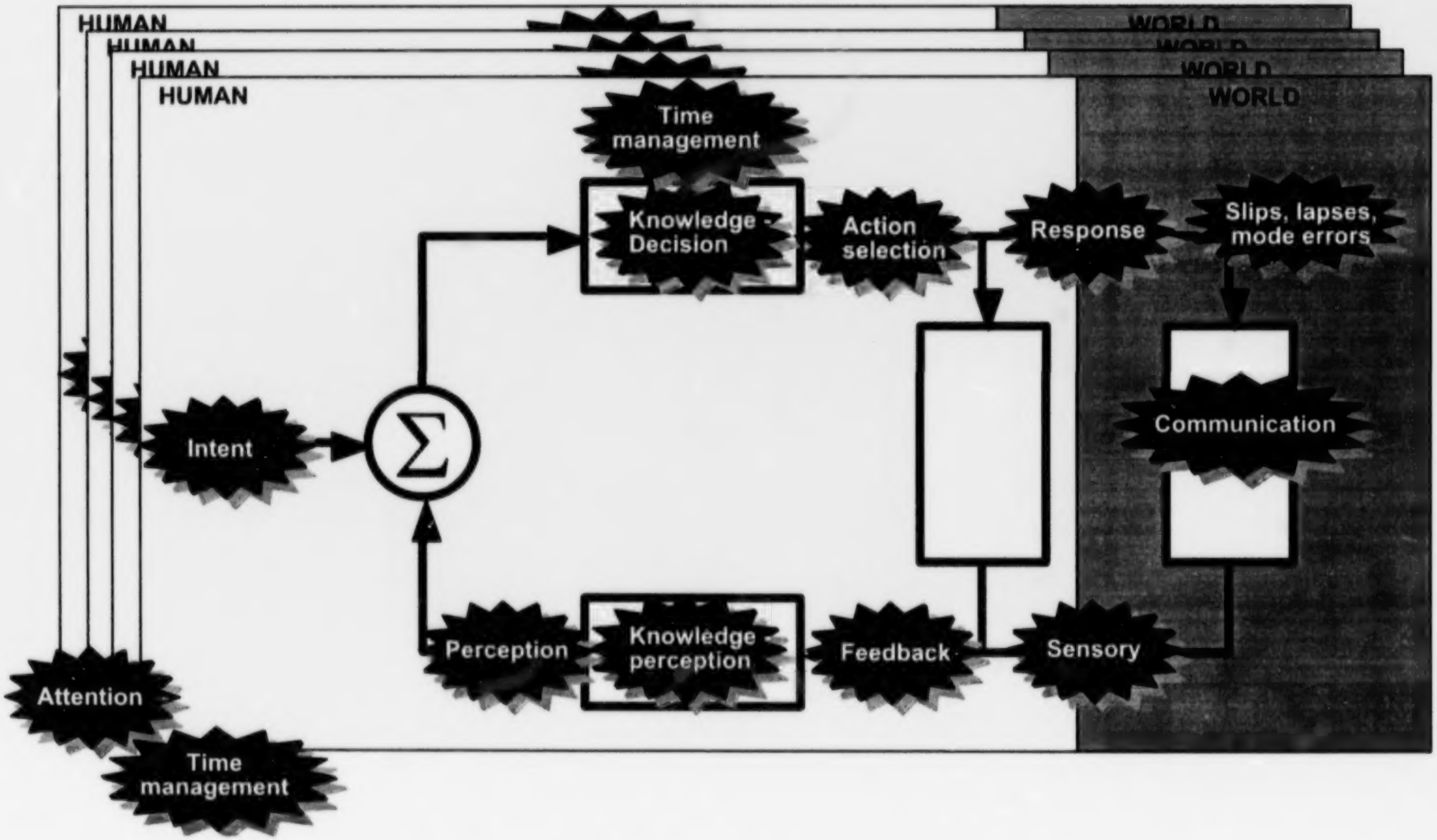
HUMAN
HUMAN
HUMAN
HUMAN
WORLD
WORLD
WORLD
WORLD
Time management
Knowledge - Decision
Action selection
Response
Slips, lapses, mode errors
Intent
Σ
Communication
Perception
Knowledge perception
Feedback
Sensory
Attention
Time management

Figure 6. Active points of failure.

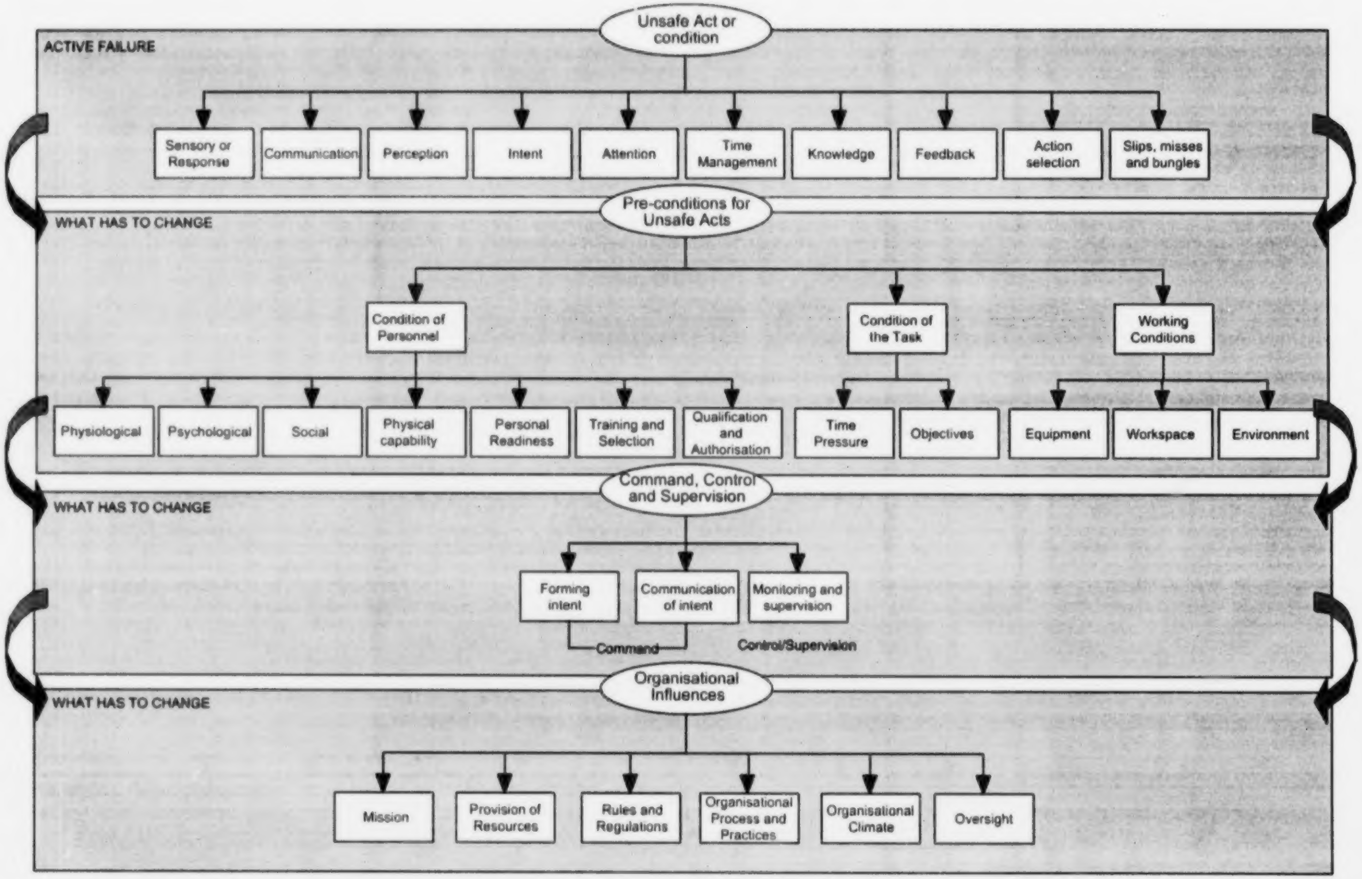
Unsafe Act or condition
ACTIVE FAILURE
Sensory or Response
Communication
Perception
Intent
Attention
Time Management
Knowledge
Feedback
Action selection
Slips, misses and bungles
Pre-conditions for Unsafe Acts
WHAT HAS TO CHANGE
Condition of Personnel
Condition of the Task
Working Conditions
Physiological
Psychological
Social
Physical capability
Personal Readiness
Training and Selection
Qualification and Authorisation
Time Pressure
Objectives
Equipment
Workspace
Environment
Command, Control and Supervision
WHAT HAS TO CHANGE
Forming intent
Communication of intent
Monitoring and supervision
Command
Control/Supervision
Organisational Influences
WHAT HAS TO CHANGE
Mission
Provision of Resources
Rules and Regulations
Organisational Process and Practices
Organisational Climate
Oversight

***Figure 7**. Active failures and three layers of pre-conditions.*

The fourth factor [S]oftware – the rules, regulations, laws, orders, SOPs, customs, practices and habits, is contained in the organisational layer of Figure 7. It is reasonable to regard the condition of the personnel [L], the condition of the hardware [H] including both displays and controls, and the condition of the physical and social environments [E] as being immediate to the active failure. This captures the conditions of the personnel in the context of the physical working environmental. The only thing missing is the condition of the task, which is implicit in the SHEL model because it defines the nature of the interactions. Therefore, the three factors of Figure 7 (**PERSONNEL**, **TASK** and **WORKING ENVIRONMENT**) appear to provide the framework for a complete classification of immediate pre-conditions.

Sitting remotely to the personnel involved in the active failure is the organisation. The organisation (or more correctly the people within the organisation) sets strategic goals in the statement of the mission, provides, develops and sustains resources to achieve that mission, establishes procedures and practices for carrying out mission related activities within the constraints of both an internally and externally imposed system of authority (rules and regulations), and creates a climate that shapes the attitudes of all who serve that organisation. The organisation must also monitor itself to see if the mission is being achieved. These endeavours capture the organisation's prime functions at this level.

The Command, Control and Supervisory process connects these two layers through a two-way flow of information (downwards through command and upwards through monitoring and supervision). These concepts will be defined in more detail later in this report.

Condition of the Personnel

The condition of the personnel is described by the following seven states. These seven states describe the condition of the individuals, working both individually and as a team or group.

- Physiological,
- Psychological,
- Social,
- Physical capability,
- Personnel readiness,
- Training and selection, and
- Qualification and authorization;

Together these conditions impact all components of the IP/PCT model and hence the human decision maker. The personnel factors are fully described in Annex A.

Condition of the task

The condition of the task is described by two factors, namely:

- the time pressure, and
- the objectives.

Together these conditions determine the two factors of the IP model (Hendy, *et al.*, 1997), that is, the time pressure personnel are under and the amount of uncertainty that has to be resolved. The objectives also define the nature of the task; they also drive goal setting and hence risk management. Detailed definitions of these factors can be found in Annex A of this Report.

Working conditions

The working conditions describe all aspects of the physical environment in which the job is performed, including the operator interface, the physical arrangement of the workspace and environmental factors such as temperature, noise, vibration, atmospheric, and weather. The working conditions are described in terms of:

- Equipment (Tools of the Trade);
- Workspace;
- Environment.

Refer to Annex A for detailed definitions of these factors.

Failures in Command, Control and Supervision

The concepts of Command, Control and Supervision used in SERA derive from PCT. Command, Control and Supervision are essentially goal driven human activities and as such they can be represented by the perceptual control loop. McCann and Pigeau (1999) define Command and Control in the following terms "...Command [is] *the creative expression of human will necessary to accomplish the mission* and Control [is concerned with] *those structures and processes devised by Command to manage risk*." If framed in PCT terms, we see that Command involves the formation and communication of the Commander's intent, while Control deals with those aspects involved in risk, and by inference **error**, management.

Hence a Command and Control process needs to support the following top-down and bottom-up activities (see Figure 8 for the representation of a Commander or Supervisor interacting with a single human operator or machine…this can be generalised from a one-to-one to a one-to-many setting by giving more operators access to the world variables):

COMMAND

Goal setting process: Forming Intent

Output process: Communicating Intent

CONTROL

Input process: Monitoring and supervision.

If we agree that a comprehensive Command and Control process should support the forming and communication of intent from the highest levels in the organization right down to the operators that are actually performing the mission activities, then supervision is also seen to be part of Command and Control. Hence, a Supervisor carries out the activities associated with the Command and Control process, but at a level appropriate to the Supervisory rather than the Command role. To complete the Command, Control and Supervisory process, those being commanded or supervised need to correctly perceive and accept the Commander's or Supervisor's intent, form appropriate goals, and carry out activities that are directed at satisfying that intent.

The performance of the whole Command, Control and Supervisory process can be assessed by measuring the appropriateness of the Formed Intent with respect to achieving objectives, by how correctly the intent is perceived (how well was the Intent Communicated) by the subject audience, and by how well ill-formed actions and Disturbances, that drive the world variables away from the desired states, are detected and corrected (**MONITORING** and **SUPERVISION**). The latter includes those actions that are deliberately contrary to the communicated intent.

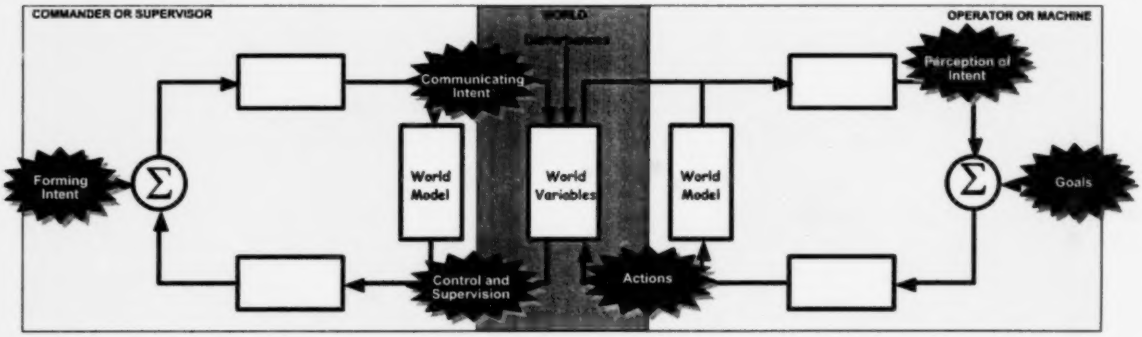

Figure 8. The Command, Control and Supervisory process.

Either humans or machines can be commanded or supervised (Hendy, Beevis, Lichacz, *et al.*, 2001). The processes shown in Figure 8 remain the same, although we might say that the machine has a set point rather than a goal (an essentially human function), and the machine might not dynamically determine the value of this set point (as does a human when forming intent). Generally a machine will merely respond to new input from the human. Until real machine intelligence emerges, machines reflect human intent rather than forming their own.

CONTROL

Input process: Monitoring and supervision.

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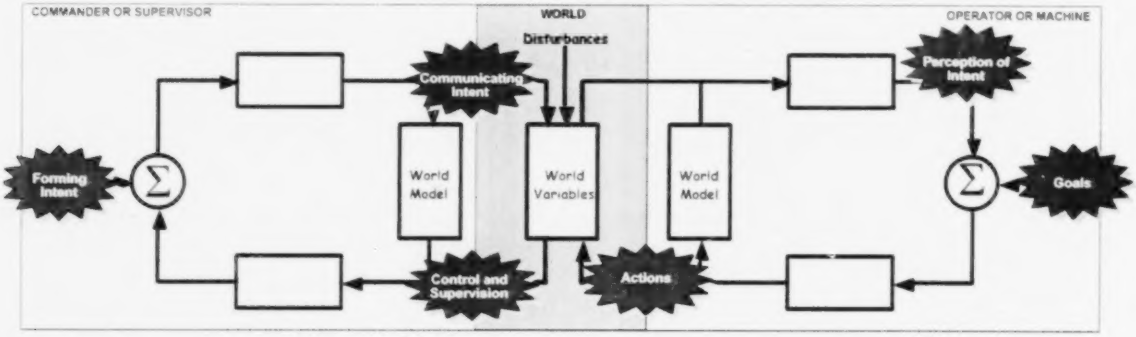

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If machines or automated systems are put in the supervisory or monitoring role[2], the functions shown on the left hand side of Figure 8 would now have to be performed by the machine. The machine would have to present the required states to those supervised and monitor progress towards these states to fulfil the supervisory function. Because the set points are usually constant, progress towards the required state is often presented in the form of the difference between a set point and the current state.

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[2] We are not yet at the situation, and may be a long way from embracing the concept, where a non-human is given Command authority. One might imagine machines in a supervisory role first.

In summary, Command, Control and Supervision are described by the following factors[3] in SERA:

- Forming Intent:
- Communication of Intent:
- Monitoring and Supervision:

In Annex A of this Report, each of these factors is described in detail.

Organizational failures

Organizational influences are at the highest level in Reason's *Latent Failure Model.* These factors potentially affect the conditions of the personnel, the task or the working conditions. They are linked to the immediate pre-conditions through the Command, Control and Supervisory process. Six organizational influences have been identified, namely:

- **MISSION**: What the organization is supposed to achieve…
- **PROVISION OF RESOURCES**: What the organization uses to achieve the mission….
- **RULES AND REGULATIONS**: Constraints on the process the organization uses to achieve the mission…
- **ORGANIZATIONAL PROCESSES,AND PRACTICES**: The way the organization should do it (i.e., achieve the mission)…
- **ORGANIZATIONAL CLIMATE**: Establishes attitudes that affect how the people in the organization perceive the mission, what they actually do, and how they actually do it…
- **OVERSIGHT**: Provides feedback so that managers can form a perception of organizational health (how well it is achieving its mission). Feedback is the stimulus for organizational change.

These processes are shown in Figure 9, mapped onto a PCT loop for the Organization. Detailed definitions of each of these factors can be found in Annex. A. If the organization is to meet the challenges of a changing world environment, this loop has to be adaptive. In other words, the mission, provision of resources, rules and regulations, processes and organizational climate may all have to adapt as circumstances change. Oversight closes the loop and provides the error correcting feedback that drives this adaptive process. Without oversight and a process for managing change, the organization will be static and unchanging. The health of the organization is perceived by those in management from data fed back through the oversight process.

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[3] Note that a very clear distinction is made between the people occupying the positions of the Commander or the Supervisor, and the processes used by these people. Obviously a Commander *commands* but also should *control*, just as a Supervisor should *form* and *communicate intent* as well as *monitor* and *supervise*. This distinction is particularly important in examining systems that have broken down. Where did supervision breakdown? Was it in the forming or communicating of the Supervisor's intent, or was it in the monitoring process used by the Supervisor? Each type of failure will require a different form of intervention.

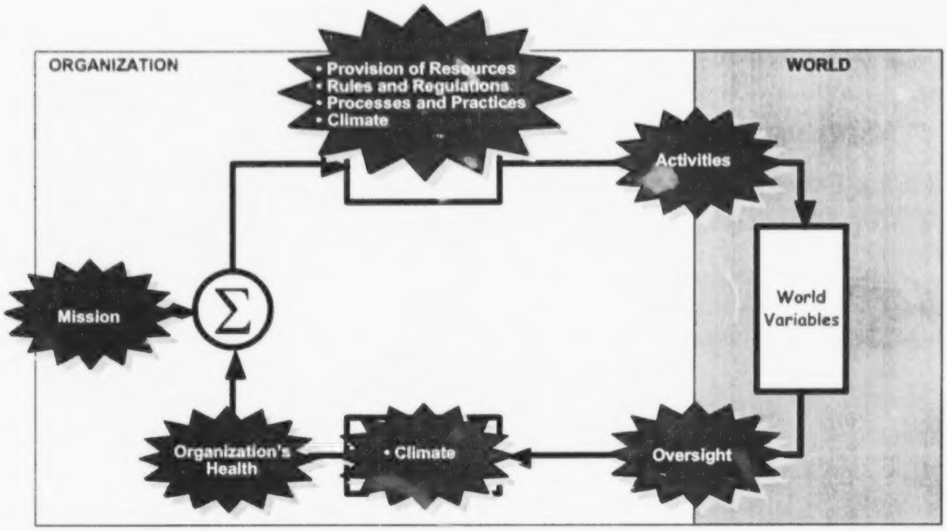
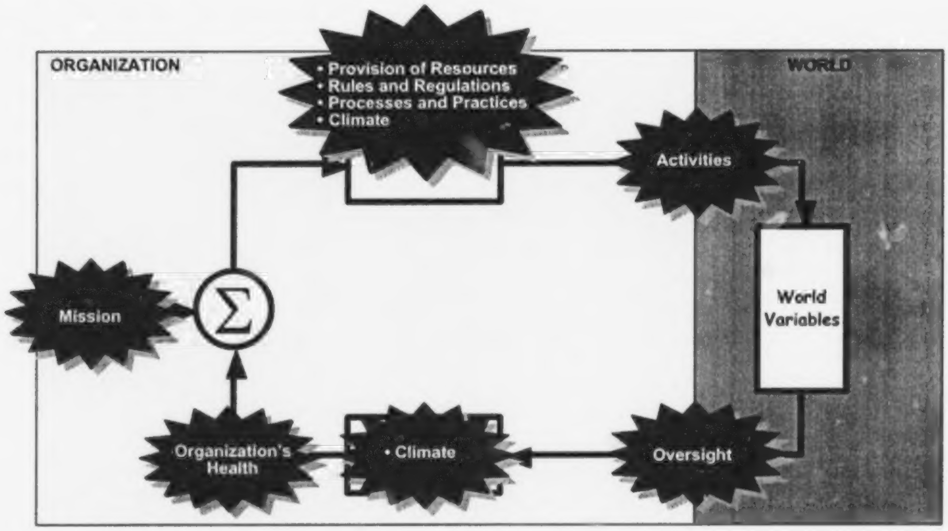


Figure 9. Organizational influences potentially contributing to active failures.

This process provides the Loop 4 level feedback in Reason's systems safety management model (see Figure 10). While the lower level loops in Figure 10 are provided by accident classification and investigation systems (e.g., HFACS, SERA) and Control and Supervisory functions, Loop 4 feedback is often missing in an organization. Note that in Figure 10, SERA's *Immediate Pre-conditions* (Personnel, Task, Working Conditions) replace Reason's more limited *Psychological Precursors*.

Linking pre-conditions with active failures

With the hierarchical breakdown of Figure 7 it is possible to link each active failure with a set of most likely pre-conditions as summarised in Table 1. The pre-conditions mark the points of intervention for the safety system as shown in Figure 11. Interventions are intended to reduce the probability that the same set of active failures will occur given similar circumstances. Active failures represent 'what happened'...but they can be traced to fundamental limitations in the human sensory, response or information processing systems. These are things that are unlikely to change, they are part of human capabilities and limitations. There is relatively little point in telling a person to attend and be more vigilant in words, the mission, provision of resources, rules and regulations, processes and organizational climate may all have to adapt as circumstances change. Oversight closes the loop and provides the error correcting feedback that drives this adaptive process. Without oversight and a process for managing change, the organization will be static and unchanging. The health of the organization is perceived by those in management from data fed back through the oversight process.



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The pre-conditions, both immediate and remote, represent 'why' the active failure existed. These are the things that have to change to prevent a recurrence because they define, either directly or indirectly, the condition of the personnel, the task and the working environment. In Annex B, immediate and remote pre-conditions are more tightly linked with each point of active failure. Their descriptions are tailored to reflect the context of each type of active failure.

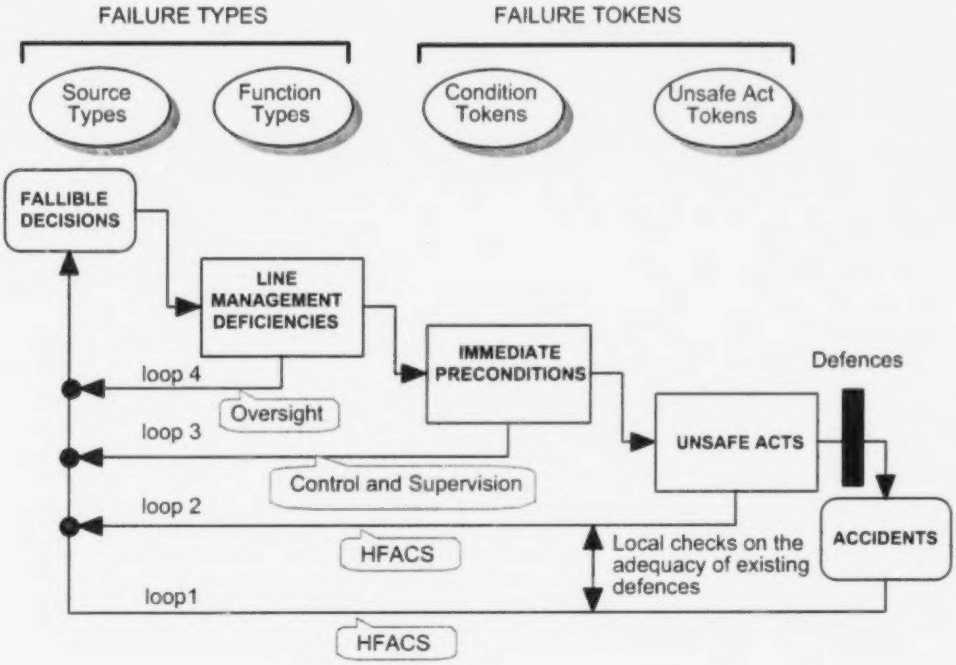
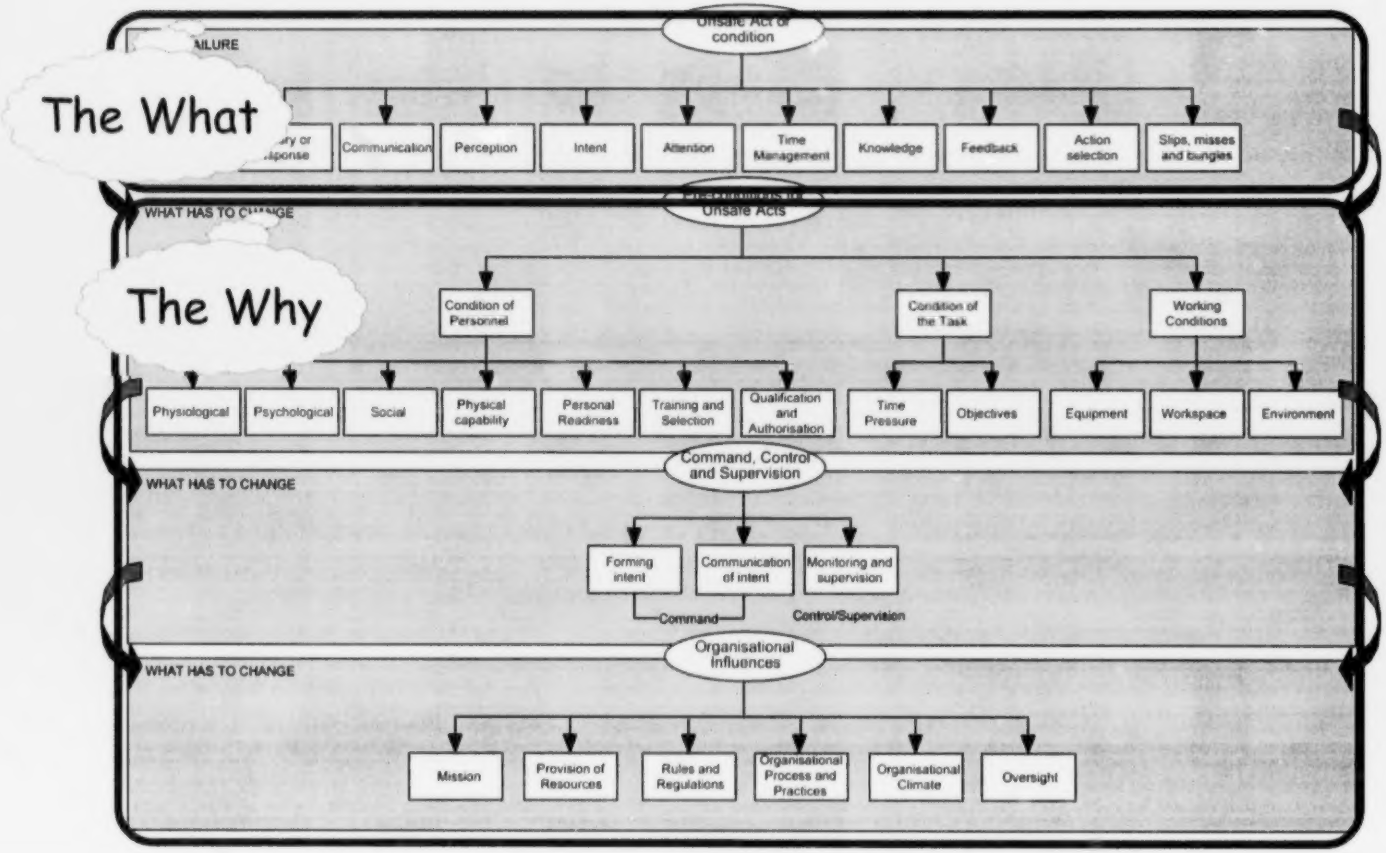

FAILURE TYPES
FAILURE TOKENS
Source Types
Function Types
Condition Tokens
Unsafe Act Tokens
FALLIBLE DECISIONS
LINE MANAGEMENT DEFICIENCIES
IMMEDIATE PRECONDITIONS
UNSAFE ACTS
Defences
ACCIDENTS
loop 4
Oversight
loop 3
Control and Supervision
loop 2
HFACS
Local checks on the adequacy of existing defences
loop1
HFACS

Figure 10. Feedback loops and indicators for the management of system safety in the Canadian Forces aviation community (after Reason, 1990, Figure 7.9).

As would be expected from PCT, the feedback process (Monitoring, Supervision, and Oversight) figures prominently in Table 1. Improvements in feedforward processes should reduce the number of active failures, but as uncertainty is introduced or as external disturbances act on the system it is feedback that provides error correction. Open loop behaviour only works when everything is certain, known and unchanging, and there are no external influences (this would be true of a closed system). Few such closed systems exist today within our complex socio-technological environment.

Table 1. *Linking active failures with pre-conditions.*

		PERSONNEL							TASK		WORKING CONDITIONS			C2 AND SUPERVISION			ORGANIZATION					
		Physiological	Psychological	Social	Physical Capability	Personal Readiness	Training and Selection	Qualification and Authorization	Time Pressure	Objectives	Equipment	Workspace	Environment	Forming Intent	Communicating Intent	Monitoring and Supervision	Mission	Provision of Resources	Rules and Regulations	Organizational Process and Practices	Organizational Climate	Oversight
FAILURES	Sensory	■			■	■	■			■	■		■			■				■		■
	Knowledge - perception						■	■		■				■	■	■	■	■		■		■
	Perception	■	■				■				■		■			■				■	■	■
	Attention	■	■	■		■	■		■		■		■			■	■	■		■	■	■
	Communication		■	■							■		■			■				■	■	■
	Time management						■		■							■	■	■				■
	Intent - violation		■	■			■	■	■	■				■	■	■			■		■	■
	Intent – non violation		■				■	■		■				■	■	■	■		■	■	■	■
	Knowledge - decision						■	■								■	■			■		■
	Response	■			■	■	■	■		■	■	■	■			■		■		■		■
	Action Selection		■						■							■	■	■				■
	Feedback	■	■	■					■		■		■			■	■	■				■
	Slips, misses, lapses						■				■								■	■		■



Unsafe Act or condition
AILURE
The What
ory or sponse
Communication
Perception
Intent
Attention
Time Management
Knowledge
Feedback
Action selection
Slips, misses and bungles
WHAT HAS TO CHANGE
Pre-conditions for Unsafe Acts
The Why
Condition of Personnel
Condition of the Task
Working Conditions
Physiological
Psychological
Social
Physical capability
Personal Readiness
Training and Selection
Qualification and Authorisation
Time Pressure
Objectives
Equipment
Workspace
Environment
Command, Control and Supervision
WHAT HAS TO CHANGE
Forming intent
Communication of intent
Monitoring and supervision
Command
Control/Supervision
Organisational Influences
WHAT HAS TO CHANGE
Mission
Provision of Resources
Rules and Regulations
Organisational Process and Practices
Organisational Climate
Oversight

Figure 11. Active failures and pre-conditions.

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A Bridge Between SERA and HFACS

As outlined in the previous Section of this Report, SERA provides an accident and incident classification system, as well as a process for identifying the points of active failure and linking them with the pre-conditions that led to these failures. While one might be well satisfied that SERA provides a comprehensive and exhaustive HF accident taxonomy, it is essential that the SERA categories can also be mapped into similar or equivalent categories within the modified HFACS classification scheme that is being adopted by the Canadian Forces (CF) Directorate of Flight Safety (DFS). This Section deals with the problem of mapping SERA categories into the CF's version of HFACS.

The Human Factors Analysis and Classification System

Whereas SERA is based on theoretical models of the human information processor, HFACS is built on what is largely a descriptive model. Shappell and Wiegmann (2000) derived their *Taxonomy of Unsafe Operations* by analysing over 300 naval aviation accidents and then refining their system with further data from Air Force, Army and civilian operations. Reason's *Latent Failure Model* provided the basic structure for their system, just as it does for SERA. Shappell and Wiegmann reject the use of "…esoteric theories with little or no practical applicability" (Shappell and Wiegmann, 2000, p. 3) in favour of a pragmatic empirical approach. Yet empirical models carry with them the possibility that the classification system is incomplete because it is constrained by the contents of the database it came from, or that it leads to redundancy and overlap between the various descriptors in the absence of an overarching theoretical framework. Evidence of this can be seen both with HFACS and with the modified version of HFACS that will be promulgated in an updated version of the guiding document for CF Flight Safety (Anon., 1999). In Table 2, the classification categories of HFACS, the CF modified version (to be referred to as AGA 135 HFACS), and SERA are compared.

Table 2. *Comparison of HFACS, AGA135 HFACS and SERA accident classification taxonomies.*

HFACS	AGA 135 HFACS	SERA
ACTIVE FAILURES		
Errors	***Errors***	***Active Failures***
Decision Errors	Decision Errors	Action Selection
Skill-Based Errors	Technique	Slips, Misses, Bungles
Perceptual Errors	Perceptual Errors	Perception
	Attention/memory	Attention
	Knowledge or Information	Knowledge

		Intent (Non-violation)
		Time Management
		Feedback
		Sensory or Response
		Communication
Violations	***Violations***	***Violations***
Exceptional	Exceptional	Intent (Exceptional violation)
Routine	Routine	Intent (Routine violation)
PRE-CONDITIONS		
Conditions of Operators	***Condition of Operators***	***Condition of Operators***
Adverse Mental States	Adverse Mental States	Psychological
Adverse Physiological States	Adverse Physiological States	Physiological
Physical/Mental Limitations	Physical/Mental Limitations	Physical Capability
Practice of Operators	***Practices of Personnel***	***Condition of Operators***
Crew Resource Mismanagement	Interpersonnel Res. Management	Social
Personal Readiness	Personal Readiness	Personal Readiness
	Training	Training and Selection
	Qualification	Qualification and Authorization
	Working Conditions	***Working Conditions***
	Equipment	Equipment
	Workspace	Workspace
	Environmental	Environment
		Condition of the Task
		Time Pressure
		Objectives
SUPERVISION		
Inadequate Supervision	Inadequate Supervision	Monitoring and Feedback
Planned Inappropriate Ops	Planned Inappropriate Ops	Forming Intent

Failed to Correct Problem	Failed to Correct Problem	Communication of Intent
Supervisory Violations	Supervisory Violations	
ORGANIZATIONAL INFLUENCES		
Resource Management	Resource Management	Provision of Resources
Organizational Climate	Organizational Climate	Organizational Climate
Organizational Process	Organizational Process	Organizational Process
		Mission
		Rules and Regulations
		Oversight

Interestingly there is no provision in HFACS, corrected under both AGA 135 HFACS and SERA, to trace the effect of deficiencies in the Working Conditions (Equipment, Workspace, and Environment) as pre-conditions to active failures. Selection, Training, Qualification and Authorization is buried in the higher level layers (Supervision and Organizational Influences) in HFACS. Only SERA considers the Rules and Regulations as potential pre-conditions to the unsafe act (not all Rules and Regulations are internally consistent and compatible with mission goals leading to systemic violations).

Transforming SERA categories into AGA 135 HFACS

Several SERA categories are not represented explicitly in either HFACS or AGA 135 HFACS although the category definitions, and some of the selected examples associated with these categories, might be interpreted to include at least some of the missing classifications (see Anon., 1999; Shappell and Wiegmann, 2000). It is really only when one tries to map each of the SERA categories into equivalent or similar AGA 135 HFACS categories that the overall picture becomes clear.

In Table 3, the SERA active failure categories are linked to the most likely AGA 135 HFACS categories. This was accomplished by reading each category descriptor, then examining the specific examples given for each type of failure, in order to find the best match. Obviously, there is a degree of subjectivity in this process but no more so than when investigators are attempting to assign cause factors from the same data source. However, it is believed that the selections in the following Tables are defensible.

Ideally each SERA category would map into one, and only one, AGA 135 HFACS category (this can't actually happen as there are 12 SERA basic active failure sub-categories and only 7 AGA 135 HFACS categories). If that was the case, then SERA and AGA 135 HFACS would be seen to be largely identical schemes, distinguished only by the names given to the categories. From Table 3 it can be seen that this is not strictly the case. In several situations a SERA category maps into more than one AGA 135 HFACS category (e.g., **SENSORY** failure), and there are also cases where more than one SERA category maps onto the same AGA 135 HFACS category (e.g., **DECISION** errors).

Table 3. *Mapping of SERA active failures into best-fit AGA 135 HFACS categories.*

SERA	AGA 135 HFACS			
ACTIVE FAILURE	**ACTIVE FAILURE**	**PRE - CONDITIONS**	**SUPERVISION**	**ORGANIZATION**
Sensory		Physical – mental limitations Personal readiness		
Response		Physical – mental limitations		
Communication	Knowledge – information			
Perception	Perceptual			
Intent – Routine violation	Violation - routine		Supervisory violations	
Intent – Exceptional violation	Violation - exceptional		Supervisory violations	
Intent – non violation	Decision			
Attention	Attention - memory			
Time management		Adverse mental state		
Knowledge - perception	Knowledge – information			
Knowledge - decision	Knowledge – information			
Feedback	Attention - memory	Adverse mental state		
Action selection	Decision Technique			
Slips, lapses and mode errors	Technique Attention - memory			

As the SERA taxonomy arguably consists of non-overlapping categories, this is evidence of some ambiguity in the AGA 135 HFACS category descriptions. In practice this ambiguity would have to be resolved by looking at the context of the unsafe act to see which AGA 135

HFACS categories are the best match. Note also that while most SERA active failures map into AGA 135 HFACS active failures, there is some drift up into the HFACS Pre-Condition and Supervisory layers. Tables 4 to 6 repeat this process for the SERA Pre-Condition, Command, Control and Supervisory, and Organizational layers.

Table 4. *Mapping of SERA Pre-Conditions into best-fit AGA 135 HFACS categories.*

SERA	AGA 135 HFACS			
PRE - CONDITIONS	**ACTIVE FAILURE**	**PRE - CONDITIONS**	**SUPERVISION**	**ORGANIZATION**
Physiological		Adverse physiological states		
Psychological		Adverse mental states		
Social		Interpersonnel resource management		
Physical capability		Physical – mental limitation		
Personal readiness		Personal readiness		
Training and selection		Training Physical – mental limitation		
Qualification and Authorization		Qualification		
Time Pressure				Organizational process
Objectives			Planned inappropriate operations	
Equipment (Tools of the trade)		Equipment		
Workspace		Workspace		
Environment		Environment		

As with Table 3, there is evidence of category drift and ambiguity in the AGA 135 taxonomy shown in Tables 4 to 6. While the mappings of Tables 3 to 6 are not one-to-one there is sufficient commonality to make the process manageable. One SERA category, **RULES AND REGULATIONS**, has no equivalent in AGA 135 HFACS.

***Table 5.** Mapping of SERA Command, Control and Supervisory failures into best-fit AGA 135 HFACS categories.*

SERA	AGA 135 HFACS			
SUPERVISION	**ACTIVE FAILURE**	**PRE - CONDITIONS**	**SUPERVISION**	**ORGANIZATION**
Forming intent			Planned inappropriate operations Supervisory violations	
Communication of intent			Inadequate supervision	
Monitoring and supervision			Inadequate supervision Failed to correct a problem	

***Table 6.** Mapping of SERA Organizational Influences into best-fit AGA 135 HFACS categories.*

SERA	AGA 135 HFACS			
ORGANIZATION	**ACTIVE FAILURE**	**PRE - CONDITIONS**	**SUPERVISION**	**ORGANIZATION**
Organizational climate				Organizational climate
Provision of resources				Resource management
Organizational process and practices				Organizational process
Mission			Planned inappropriate operations	Organizational process Resource management
Rules and Regulations				
Oversight				Organizational process

Risk Management

The pre-conditions (both immediate and remote) shown in Figure 11, under the banner "The Why", are the factors that must change in order to break the causal chain that leads to the existence of an unsafe act or condition. Hence, control of these factors is the key to risk management, thus making a natural linkage between an error taxonomy and a potential risk management tool. These factors fall easily into two classes that are seen to provide risk management at both:

- the Tactical (immediate) level, and
- the Strategic (remote) level.

Tactical risk management

Tactical risk management involves the control of those factors that are closest to a potential unsafe act or condition. Hence, tactical risk assessment should be based on the states of the following factors:

CONDITION OF THE PERSONNEL

Physiological,

Psychological,

Social,

Physical capability,

Personal readiness,

Training and selection,

Qualification and authorization.

CONDITION OF THE TASK

Time Pressure,

Objectives.

WORKING CONDITIONS

Equipment,

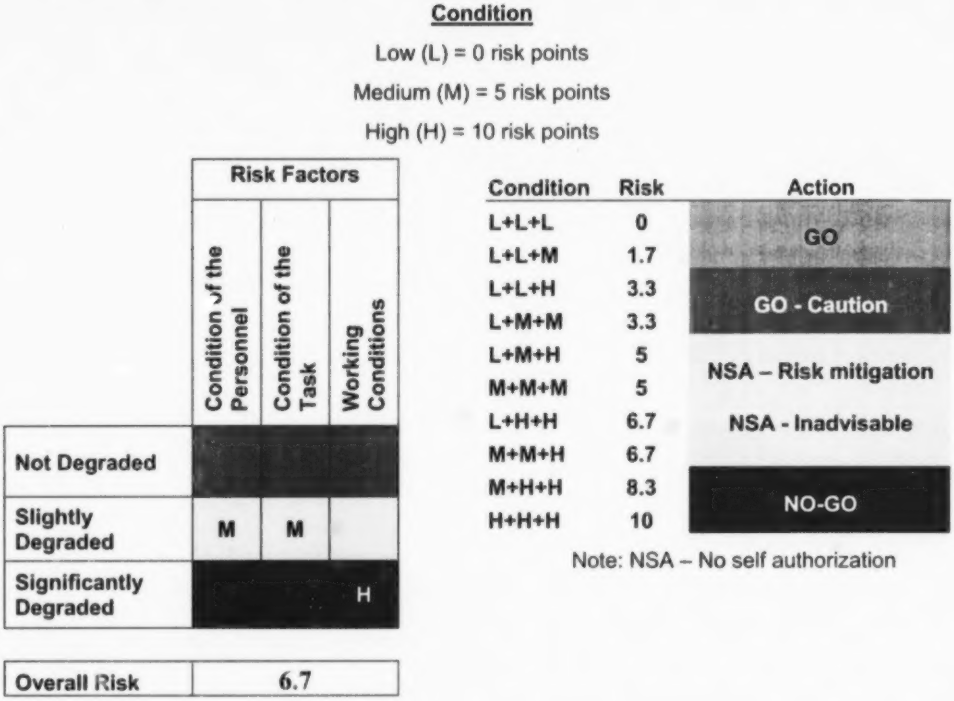
Workspace,

Environment.

A detailed tactical risk assessment tool should be based on the assessment of all twelve of these factors, while a simple tool might use just the three higher-level factors (i.e., **CONDITION OF THE PERSONNEL**,**C ONDITION OF THE TASK**, and the **WORKING**

CONDITIONS). One of these factors (**QUALIFICATION AND AUTHORIZATION**) should be purely a GO, NO-GO criterion. Unqualified and un-authorised personnel should not be used in operations unless it is in exceptional circumstances. Qualification and Authorization is likely more a legal issue than a risk assessment issue. The operational impact of using unqualified and un-authorised personnel will generally be reflected in the state of the other personnel factors (level of training, physical capability for the task etc.).

Figures 12 and 13 demonstrate what a simple risk assessment checklist, derived from the SERA categories, might look like. It should be noted that these examples have in no way been validated – they are for demonstration purposes only. In all of the following examples the mathematical forms are notional and offered only as straw men to demonstrate how a risk assessment tool might be constructed.



Condition

Low (L) = 0 risk points

Medium (M) = 5 risk points

High (H) = 10 risk points

	Risk Factors		
	Condition of the Personnel	Condition of the Task	Working Conditions
Not Degraded			
Slightly Degraded	M	M	
Significantly Degraded			H

Overall Risk	6.7

Condition	Risk	Action
L+L+L	0	GO
L+L+M	1.7	
L+L+H	3.3	GO - Caution
L+M+M	3.3	
L+M+H	5	NSA – Risk mitigation
M+M+M	5	
L+H+H	6.7	NSA - Inadvisable
M+M+H	6.7	
M+H+H	8.3	NO-GO
H+H+H	10	

Note: NSA – No self authorization

Figure 12. *A tactical risk assessment tool based on three SERA factors.*

In the first example a simple linear model was used to assign a numerical value to the level of risk associated with various degraded states. This was based on an assignment of 0 risk points if a condition is not degraded, 5 if slightly degraded, and 10 if significantly degraded. The results for the three factors, in Figure 12, were then rolled up by the following equation to give an overall risk figure ($0 \le Risk \le 10$).

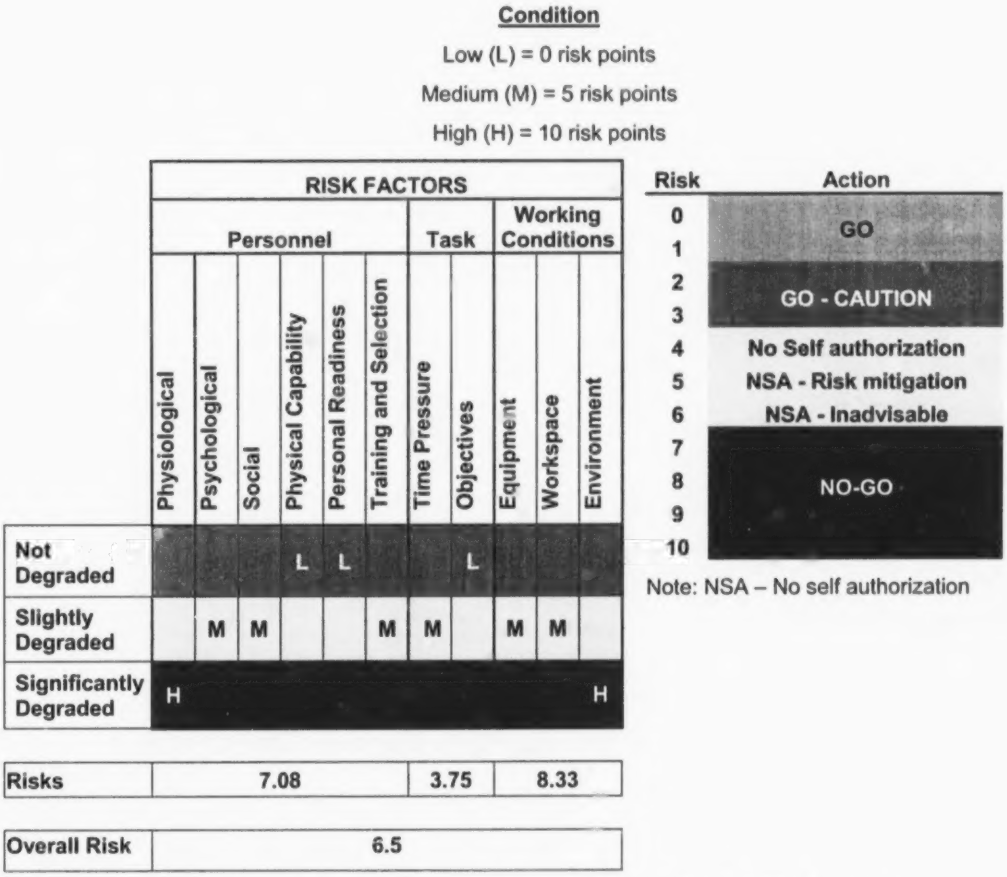
$$Risk = \frac{(P + T + W)}{3},$$

where: *P* = *Personnel*, *T* = *Task* and *W* = *Working Conditions*. At 5 overall risk points, a higher level of supervisory oversight and risk mitigation might be called for (see Figure 12). At 7 overall risk points, operations should cease unless operational considerations make it essential. Again these recommended actions, and the levels at which they are to be applied, are notional and are for demonstration only. Obviously a tool such as this must be validated.

A more detailed tool, using all eleven immediate pre-conditions, is shown in Figure 13. Note that Qualification and Authorization is again considered to be a GO, NO-GO criterion. A linear model of 0, 5, and 10 risk points is used for three levels of degradation (none, slight, significant). An overall level of risk is calculated by the following equation:

$$Risk = \frac{1.4(Max(P)+Mean(P))+0.8(Max(T)+Mean(T)+Max(W)+Mean(W))}{6},$$

where: *P* = *Personnel*, *T* = *Task* and *W* = *Working Conditions*.



Condition

Low (L) = 0 risk points

Medium (M) = 5 risk points

High (H) = 10 risk points

	RISK FACTORS										
	Personnel						Task		Working Conditions		
	Physiological	Psychological	Social	Physical Capability	Personal Readiness	Training and Selection	Time Pressure	Objectives	Equipment	Workspace	Environment
Not Degraded				L	L			L			
Slightly Degraded		M	M			M	M		M	M	
Significantly Degraded	H										H

Risk	Action
0	GO
1	
2	GO - CAUTION
3	
4	No Self authorization
5	NSA - Risk mitigation
6	NSA - Inadvisable
7	NO-GO
8	
9	
10	

Note: NSA – No self authorization

Risks	7.08	3.75	8.33

Overall Risk	6.5

Figure 13. A tactical risk assessment tool based on eleven SERA factors.

CONDITIONS). One of these factors (**QUALIFICATION AND AUTHORIZATION**) should be purely a GO, NO-GO criterion. Unqualified and un-authorised personnel should not be used in operations unless it is in exceptional circumstances. Qualification and Authorization is likely more a legal issue than a risk assessment issue. The operational impact of using unqualified and un-authorised personnel will generally be reflected in the state of the other personnel factors (level of training, physical capability for the task etc.).

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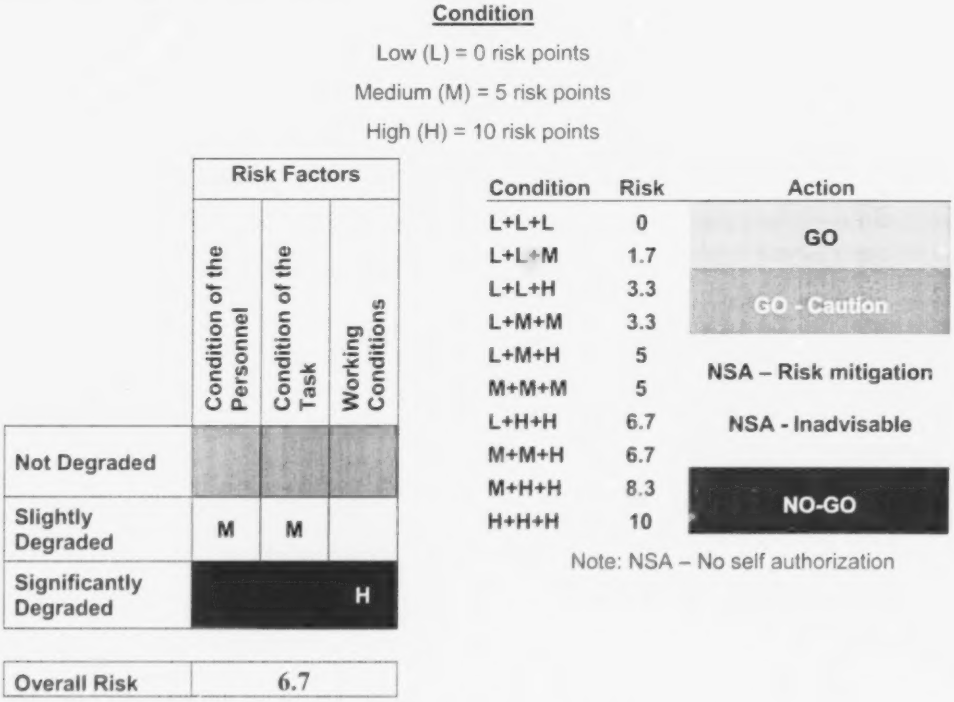


Condition

Low (L) = 0 risk points

Medium (M) = 5 risk points

High (H) = 10 risk points

	Risk Factors		
	Condition of the Personnel	Condition of the Task	Working Conditions
Not Degraded	▨	▨	▨
Slightly Degraded	M	M	
Significantly Degraded	■	■	H
Overall Risk	6.7		

Condition	Risk	Action
L+L+L	0	GO
L+L+M	1.7	
L+L+H	3.3	GO - Caution
L+M+M	3.3	
L+M+H	5	NSA – Risk mitigation
M+M+M	5	
L+H+H	6.7	NSA - Inadvisable
M+M+H	6.7	
M+H+H	8.3	NO-GO
H+H+H	10	

Note: NSA – No self authorization

Figure 12. A tactical risk assessment tool based on three SERA factors.

In the first example a simple linear model was used to assign a numerical value to the level of risk associated with various degraded states. This was based on an assignment of 0 risk points if a condition is not degraded, 5 if slightly degraded, and 10 if significantly degraded. The results for the three factors, in Figure 12, were then rolled up by the following equation to give an overall risk figure ($0 \leq Risk \leq 10$).

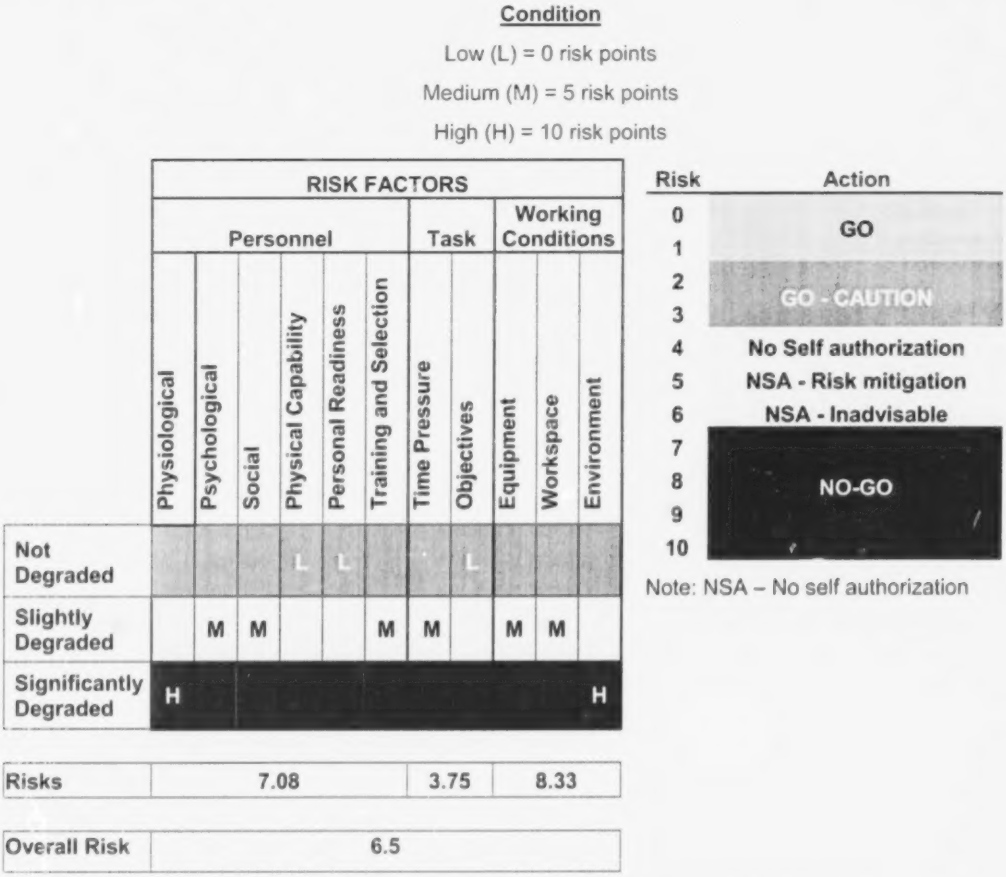
$$Risk = \frac{(P + T + W)}{3},$$

where: *P* = *Personnel*,*T* = *Task* and *W* = *Working Conditions*. At 5 overall risk points, a higher level of supervisory oversight and risk mitigation might be called for (see Figure 12). At 7 overall risk points, operations should cease unless operational considerations make it essential. Again these recommended actions, and the levels at which they are to be applied, are notional and are for demonstration only. Obviously a tool such as this must be validated.

A more detailed tool, using all eleven immediate pre-conditions, is shown in Figure 13. Note that Qualification and Authorization is again considered to be a GO, NO-GO criterion. A linear model of 0, 5, and 10 risk points is used for three levels of degradation (none, slight, significant). An overall level of risk is calculated by the following equation:

$$Risk = \frac{1.4(Max(P) + Mean(P)) + 0.8(Max(T) + Mean(T) + Max(W) + Mean(W))}{6},$$

where: *P* = *Personnel*,*T* = *Task* and *W* = *Working Conditions*.



Condition

Low (L) = 0 risk points

Medium (M) = 5 risk points

High (H) = 10 risk points

	RISK FACTORS										
	Personnel						Task		Working Conditions		
	Physiological	Psychological	Social	Physical Capability	Personal Readiness	Training and Selection	Time Pressure	Objectives	Equipment	Workspace	Environment
Not Degraded				L	L			L			
Slightly Degraded		M	M			M	M		M	M	
Significantly Degraded	H										H

Risks	7.08	3.75	8.33

Overall Risk	6.5

Risk	Action
0	GO
1	
2	GO - CAUTION
3	
4	No Self authorization
5	NSA - Risk mitigation
6	NSA - Inadvisable
7	NO-GO
8	
9	
10	

Note: NSA – No self authorization

Figure 13. *A tactical risk assessment tool based on eleven SERA factors.*

This equation gives more weight (1.4 versus 0.8) to the personnel factor than to the task and the working conditions. The use of the maximum risk value, as well as the mean, gives emphasis to a single high-risk factor whereas taking the mean alone averages out the contribution of a single large value (particularly as the number of items increases). Again it should be noted that these calculations are notional and are for demonstration purposes only.

Strategies for managing risk

Aviation and particularly military aviation is never risk free. There is always a place for managing and mitigating the risk of operations. But when the risk factors start to accumulate (say at risk values of 4 and higher in Figures 12 and 13) , risk mitigation becomes essential.

From the IP/PCT model the lines of defence from which a risk mitigation process can be implemented are:

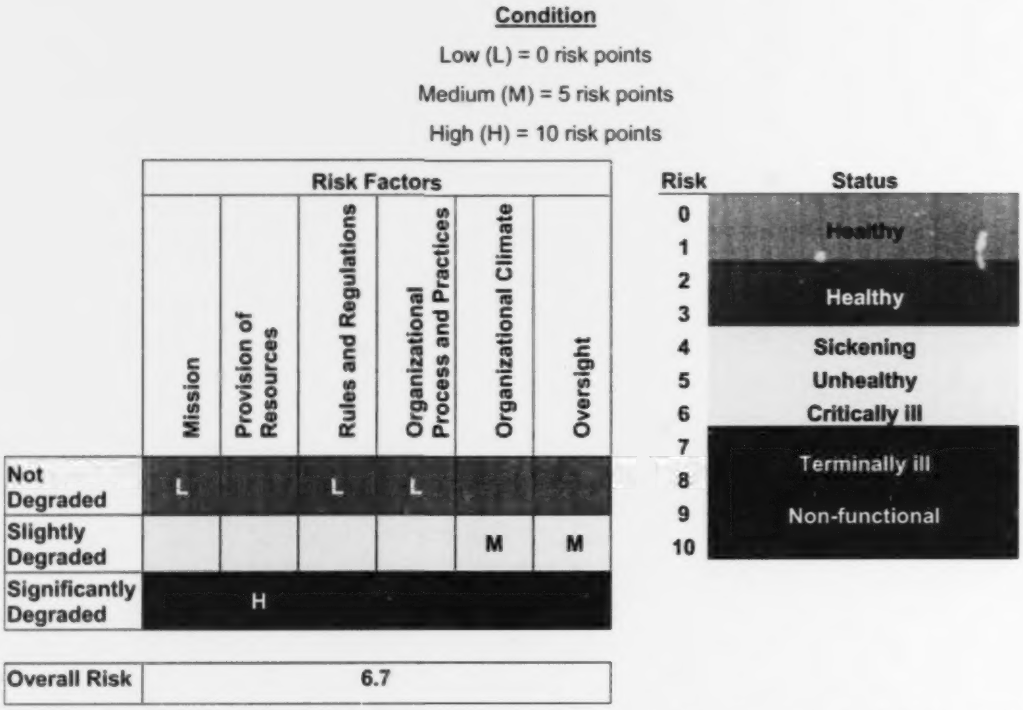
- Goal setting: the first line of defence in risk management.
    - If there are choices, choose the more conservative option.
    - Make sure that everyone in the team understands and agrees on the goals.
- Action selection: the second last line of defence in risk management.
    - Reduce information processing load by reducing uncertainty.
    - Use SOPs, avoid shortcuts or using unrehearsed or unfamiliar plans of action.
    - Pre-plan actions (including fall back plans) and take control of the timeline.
    - Plan in depth based on an [A]wareness of the situation, the [I]mplications of the situation, and make a [P]lan to achieve the goal.
    - Keep the 'back door open' in case the situation degrades further. This plan may have to be refreshed as the situation changes.
- Feedback: the last line of defence in risk management.
    - Increase the level of supervision, monitoring and crosschecking. Monitor yourself and crosscheck others. Ask of yourself and others "...what are we trying to achieve, what do we think is happening, what's the plan?"
    - Constantly maintain feedback and monitor progress towards the goals.
    - Ensure that all critical variables are being controlled (attended to).
    - Act (set new goals, modify the plan of action) if diverging from the goals.

Strategic risk management

Strategic risk management starts with an assessment of the six organizational level factors from Figure 7. These are:

- Mission
- Provision of Resources
- Rules and Regulations
- Organizational Process and Practices
- Organizational Process
- Oversight.

Figure 14 is an example of a simple tool to assess the risk at the organizational level based on these six SERA factors.



Condition

Low (L) = 0 risk points

Medium (M) = 5 risk points

High (H) = 10 risk points

	Risk Factors					
	Mission	Provision of Resources	Rules and Regulations	Organizational Process and Practices	Organizational Climate	Oversight
Not Degraded	L		L	L		
Slightly Degraded					M	M
Significantly Degraded		H				

Overall Risk	6.7

Risk	Status
0	Healthy
1	
2	Healthy
3	
4	Sickening
5	Unhealthy
6	Critically ill
7	Terminally ill
8	
9	Non-functional
10	

Figure 14. A strategic risk assessment tool for assessing the health of an organization based on six SERA factors.

Strategic risk management

Strategic risk management starts with an assessment of the six organizational level factors from Figure 7. These are:

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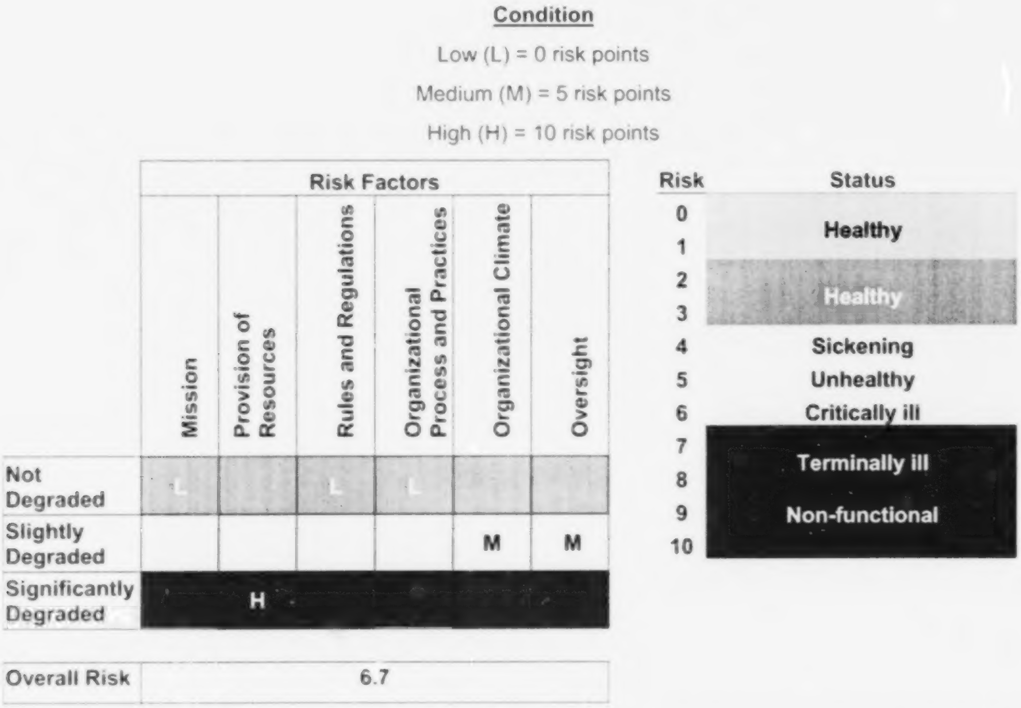

Condition

Low (L) = 0 risk points

Medium (M) = 5 risk points

High (H) = 10 risk points

	Risk Factors					
	Mission	Provision of Resources	Rules and Regulations	Organizational Process and Practices	Organizational Climate	Oversight
Not Degraded	L		L	L		
Slightly Degraded					M	M
Significantly Degraded		H				

Overall Risk	6.7

Risk	Status
0	Healthy
1	
2	Healthy
3	
4	Sickening
5	Unhealthy
6	Critically ill
7	
8	Terminally ill
9	Non-functional
10	

Figure 14. A strategic risk assessment tool for assessing the health of an organization based on six SERA factors.

Overall risk is again calculated, for the purposes of demonstration, using both the maximum value of risk and the average of all risk values as follows:

$$Risk = \frac{1}{2}\left[\max\{f_1, f_2, \ldots, f_6\} + \frac{1}{6}\sum_{i=1}^{6} f_i\right],$$

where: f_i is the score for the *i*th risk factor.

In each of these examples linear or variations on linear models have been used. Other models with more direct application to human decision-making might be considered such as Baconian logic models or fuzzy models (e.g., see Cohen, 1977; McNeill and Freiberger, 1993).

Validation

The tools presented in Figures 12 to 14 are not intended for immediate implementation but are offered as a demonstration of concepts. The mathematical formulations used are purely notional and have solid basis in theory. Tools such as these would need to be validated before bringing them into operational use. A starting point for the validation process would be to apply these tools to routine operations for a period of time and also to a set of accident and incident reports.

The expectation would be that routine operations would score almost exclusively in the green or GO region of the risk scale, unless the organisation is in a state of crises. The pre-conditions to many incidents and accidents would be expected to register in the yellow (Caution) or red (NO-GO) zones. Note that the concept for these tools is that they would be applied a priori, that is, prior to the mission. Therefore they will not capture factors that changed during the mission, for example, deteriorating weather, increasing time pressure, or non-anticipated physiological and psychological degradation due to fatigue. Nor will they capture factors that lie dormant and do not emerge until the accident or incident investigation.

A Software Application for Implementing SERA

A software application has been designed as an aid to applying SERA. This Java™ application implements the process described in Annex B to this Report. The application currently has been implemented on the Macintosh platform but the use of Java™ as the programming language makes its porting to other platforms a straight forward process. The application, as it currently exists, was developed as a proof-of-concept demonstration of how the SERA process could be aided. There is considerable scope for further improvement of the tool.

The SERA application presents a series of screens that leads the analyst one step at a time through the process outlined in Annex B. A graphical aid to navigation shows where one is in this activity at all times, and can be used to return to any step with a double click on any of the boxes visited previously. Figure 15 shows a typical SERA data entry screen with the navigation aid alongside.

The analysis starts with the identification of an unsafe act. Currently SERA v1.0 deals with one unsafe act at a time. A useful modification of the SERA software would provide an ability to identify and analyse multiple unsafe acts within a single SERA file. One can of course generate a series of files with the current version of SERA to cover multiple unsafe acts, but this complicates record keeping.

Once a point of failure has been identified the analyst is asked to choose the SERA preconditions that were associated with this failure. The most likely pre-conditions are presented first, followed by a listing of all remaining SERA factors. An additional screen allows one to detail factors that are outside the SERA taxonomy. All screens contain a field for extensive comments and supporting material. A rigorous tracking of missed steps, unanswered questions, and internal consistency reduces the chance that the analysis will be incomplete or the process inappropriately applied. SERA automatically links the SERA failures and pre-conditions with the closest AGA 135 HFACS categories as outlined previously in this report. In future versions of the SERA application the analyst will be able to overturn the automatic selections if so inclined.

Once all failures and pre-conditions have been identified, SERA consolidates all the data, including comments and supporting material, into a text file that constitutes a first cut at the final report.

An Example of using the SERA Application

To test the functioning of the software, SERA was applied to an accident from the National Transportation Safety Board (NTSB) aviation accident database[4]. The results of that analysis are shown in Annex C to this Report. The accident involved a case of fuel exhaustion that occurred soon after take off on a local VFR flight.

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[4] See http://www.ntsb.gov/NTSB/query.asp for access to this facility.

Potentially there are several unsafe acts that might be analysed in this example. The first, and most obvious, is the act of initiating a flight with less than the required amount of fuel on board. This is the unsafe act that was subjected to the full SERA analysis shown in Annex C.

At least two additional unsafe acts occurred that could also be analysed with SERA. The first relates to emergency procedures following a partial loss of engine power. In addition to the use of the auxiliary fuel pump, a normal emergency procedure would dictate changing tanks. From the accident report it appears that the right tank contained more fuel than the left (which was found to be empty in a post accident inspection). Due to the low altitude of the aircraft (400-500ft AGL) time pressure would have been a factor in successfully actioning a complete emergency check list while manoeuvring the aircraft for a potential off-airport landing. It was assumed that the engine was drawing from the left tank when the first loss of engine power occurred. Here the active failure is likely to be found in ACTION selection and implementation. This might lead to the identification of an underlying lack of knowledge unless the pilot can recite a full engine failure check list, or to a memory retrieval failure if the check list was known but was not fully implemented in this situation.

Another unsafe act that could be analysed is the decision to turn back to the airfield while only 400-500ft AGL. A 180 degree turn at this altitude and with no engine power is unlikely to be successful. Using SERA a series of questions might have been asked by the investigator to see if the pilot understood the perils of a 180 degree turn at low altitude (raising a possible question as to whether this material is being taught in flight school) and whether this decision was guided by a perception that enough engine power was being developed to make the manoeuvre possible. As it turned out the occupants were somewhat lucky to have escaped with minor injuries.

Annex C contains a slightly edited version of the text file produced by SERA. Pre-conditions that were considered not to be active in this accident were removed from the file and slight re-ordering of the material allowed common data to be grouped together. Otherwise Annex C is a faithful representation of report generation capability of SERA v1.0. Future enhancements to SERA will address issues related to the ordering and presentation of material in the report, and will likely mirror the format of Annex C.

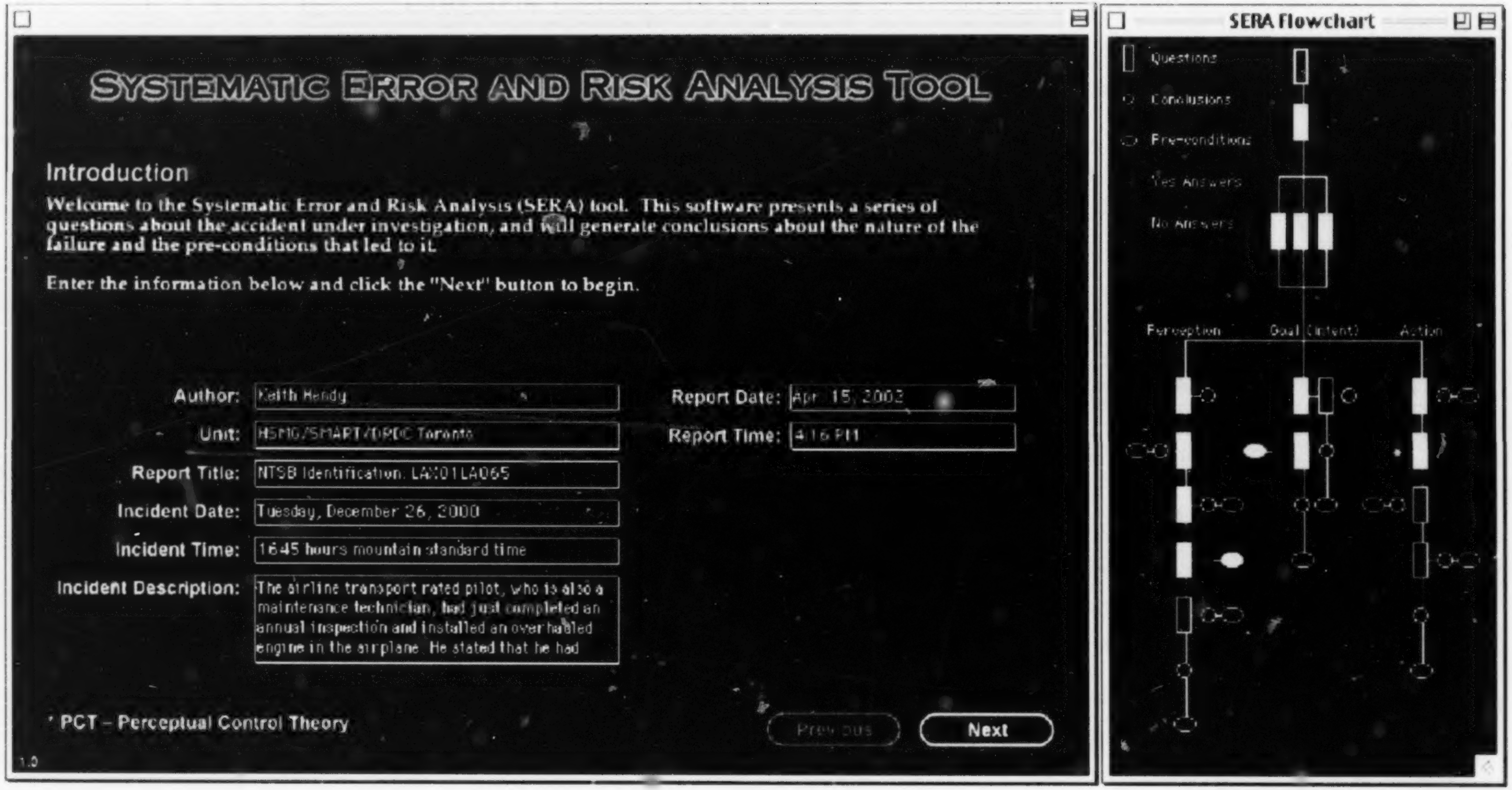
The NTSB attributed this accident to "…the pilot's improper preflight and failure to refuel the airplane." This does not address the issue of why an experienced pilot (holding an ATP and maintenance technician qualifications) did not know what the actual fuel state was, despite a visual check of the tanks and first hand knowledge of the recent flight history of the aircraft. No remedial action flows from the NTSB diagnosis.

On the other hand SERA identified two active failures and two pre-conditions from the first unsafe act, as follows:

Active Failures

> PERCEPTUAL FAILURE: An incorrect perception was formed because conflicting and ambiguous information was not resolved.

EXCEPTIONAL VIOLATION: The pilot unknowingly broke rules related to the amount of usable fuel required for the flight.



SYSTEMATIC ERROR AND RISK ANALYSIS TOOL

Introduction

Welcome to the Systematic Error and Risk Analysis (SERA) tool. This software presents a series of questions about the accident under investigation, and will generate conclusions about the nature of the failure and the pre-conditions that led to it.

Enter the information below and click the "Next" button to begin.

Author: Keith Hendy

Unit: HSMG/SMART/DRDC Toronto

Report Title: NTSB Identification: LAX01LA065

Incident Date: Tuesday, December 26, 2000

Incident Time: 1645 hours mountain standard time

Incident Description: The airline transport rated pilot, who is also a maintenance technician, had just completed an annual inspection and installed an overhauled engine in the airplane. He stated that he had

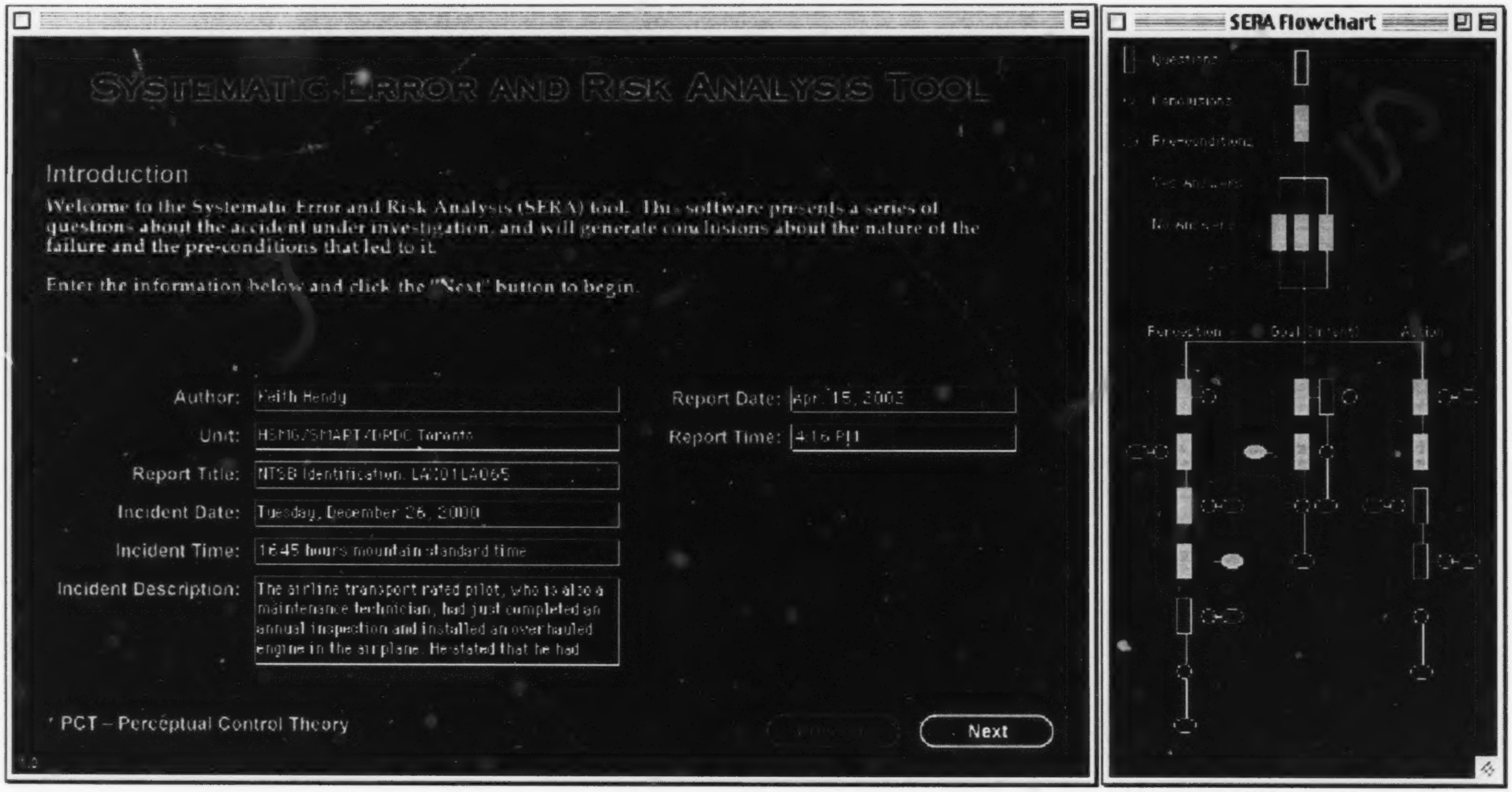
Report Date: Apr. 15, 2003

Report Time: 4:16 PM

* PCT – Perceptual Control Theory

Previous
Next
1.0
SERA Flowchart
Questions
Conclusions
Pre-conditions
Yes Answers
No Answers
Perception
Goal (Intent)
Action

Figure 15. A typical screen in the SERA Java™ application.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Questions
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Goal (Intent)
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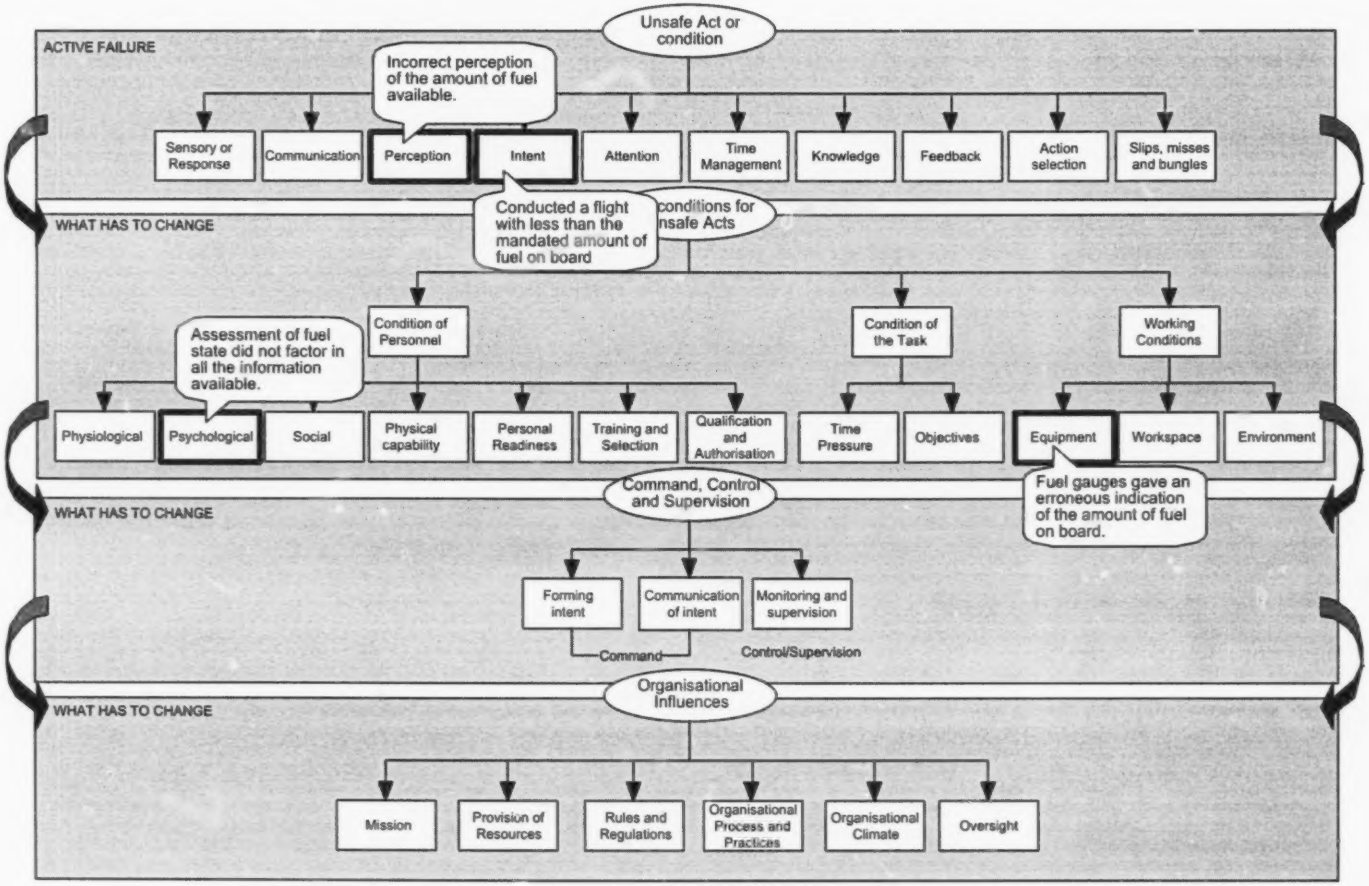
Unsafe Act or condition
ACTIVE FAILURE
Incorrect perception of the amount of fuel available.
Sensory or Response
Communication
Perception
Intent
Attention
Time Management
Knowledge
Feedback
Action selection
Slips, misses and bungles
WHAT HAS TO CHANGE
Conducted a flight with less than the mandated amount of fuel on board
conditions for nsafe Acts
Condition of Personnel
Condition of the Task
Working Conditions
Assessment of fuel state did not factor in all the information available.
Physiological
Psychological
Social
Physical capability
Personal Readiness
Training and Selection
Qualification and Authorisation
Time Pressure
Objectives
Equipment
Workspace
Environment
Fuel gauges gave an erroneous indication of the amount of fuel on board.
Command, Control and Supervision
WHAT HAS TO CHANGE
Forming intent
Communication of intent
Monitoring and supervision
Command
Control/Supervision
Organisational Influences
WHAT HAS TO CHANGE
Mission
Provision of Resources
Rules and Regulations
Organisational Process and Practices
Organisational Climate
Oversight

Figure 16. *Active failures and pre-conditions arising from a SERA analysis of an incident report from the NTSB data base (NTSB Identification: LAX01LA065).*

Pre-Conditions

> EQUIPMENT: Gauging tank contents by a visual inspection is unreliable unless a calibrated dip stick is used. The aircraft fuel gauges were poorly calibrated and gave a very optimistic picture regarding fuel on board.
>
> INFORMATION PROCESSING BIASES: The information was attended to selectively, or was ignored. Conflicting information was not integrated and the discrepancy resolved.

One pre-condition identifies a problem with the accuracy of fuel gauges in this aircraft or type of aircraft and the other leads to a potential need to have pilots routinely verify fuel contents by at least two independent routes.

This level of analysis provides useful data for tracking trends and for designing interventions to deal with emergent human factors issues. The factors identified by SERA in this accident, and the potential interventions, are different to those that might be found in a situation where a pilot didn't bother to check the fuel state prior to departure, knew exactly how many gallons were on board but had no notion of the fuel burn per hour, or deliberately undertook a flight with no reserve. The NTSB conclusions, on the other hand, may not change, as they are neutral with respect to the underlying human factors reasons behind the decisions that were made.

Testing the Reliability of SERA

It is planned to establish the reliability of the SERA process using the Java™ application to guide the analysis. 20 cases have been drawn from the NTSB database from calendar year 2001. The criterion for selection were:

- Final reports were used so that the facts of the case had been checked and a full narrative was available. This also meant that the NTSB's most probable cause had been assigned and this outcome can be compared with the SERA analysis.
- Only cases that appeared to involve human factors issues were considered. Straight equipment failures were rejected.
- Only cases with a sufficiently detailed narrative were selected. This meant that in all cases a crewmember or passenger survived the accident. Only two out of the 20 cases involved a fatality.

In each case a point of departure from safe operation has been identified and an unsafe act or condition described. This step is common to all accident investigation processes and is not specific to SERA. Hence, any variability due to the identification of the unsafe act should not be lumped in with an assessment of the SERA process proper.

It is intended to have a group of investigators apply SERA, by way of the Java™ application, to the set of NTSB accidents so that inter-rater reliability can be established. A measure of inter-rater reliability should look for cases of agreement and disagreement amongst analysts.

In the current context, agreement between two analysts is signalled by the inclusion of the same failure category for the same case, or alternatively by the common omission of a category.

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Discussion

The primary objective of this work was to develop a tool for investigating the human factors issues of accidents and incidents using the strong theoretical position afforded by the IP/PCT model (Hendy, *et al.*, 2001b). Additional objectives were to link the outcome of the resulting tool (designated SERA) with an established taxonomy for accident investigation, namely, a version of the Human Factors Accident Classification System or HFACS (Shappell and Wiegmann, 2000). A final goal was to extend SERA as a prototype risk management tool. All these objectives have been met.

SERA is a tool for accident and incident investigation, but it also provides a comprehensive stand-alone taxonomy of human 'error'. A comparison of SERA with HFACS and the AGA 135 version of HFACS leads to the following comparisons:

- SERA provides a more comprehensive taxonomy of active failures than either HFACS or AGA 135 HFACS (12 versus 3 versus 5 categories).
- SERA provides a more comprehensive taxonomy of immediate pre-conditions than either HFACS or AGA 135 HFACS (12 versus 5 versus 10 categories).
- SERA provides a more comprehensive taxonomy of organizational influences than either HFACS or AGA 135 HFACS (6 versus 3 versus 3 categories).

As an investigative tool SERA can interface with other classification systems such as HFACS, essentially serving as a front-end for data entry into HFACS. The decision ladders of SERA, shown in Figure 5 of this Report, guide the investigative process (including the interview process) to the active points of failure through a series of common sense questions. For example:

"*...what did the operator believe was happening*?"

"*...was it a correct or adequate assessment*?"

"*...did the operator have the capability to sense and perceive the situation*?"

"*...was the time pressure excessive*?"

The response to most of these questions is simply YES or NO. While the requirements of human factors investigations are rarely trivial, this structured plain language process greatly eases the need for the investigator to have extensive human factors training or knowledge.

The answers to the questions embedded in Figure 5 hold the key to understanding what went wrong. Annex B attempts to put this process into words, but while each step is relatively simple, the total amount of material contained in Annex B is somewhat daunting. It is expected that one might refer to the text of Annex B only in the first few applications of

SERA. Thereafter, the decision ladders of Figure 5 may provide sufficient guidance to implement the process once one is familiar with the basic concepts.

SERA could be made less complex if the material of Annex B was shown only in the context of the investigator's current place in the overall process. SERA could be easily programmed into a decision-aiding tool that would run on a Personal Digital Assistant (PDA) or laptop computer. This might either be stand-alone or made available in a web-based application. Now the content of Annex B would appear one screen at a time, to support the investigator in negotiating the current step in the decision process. Additional material could be displayed to the novice, or if specifically requested by the user (e.g., What is meant by… [Capability, Time Pressure etc.]?). The investigator could insert descriptive material at each step to justify every YES-NO decision. Once the process is completed, the inserted text could be collected and automatically assembled into a first cut at the draft report. The database built during the analysis might be archived and embedded as an object within the HFACS database structure thus retaining the contents of the SERA analysis. A limited capability proof-of-concept application, with these properties, is demonstrated and described briefly in this report.

Familiarity with the underlying concepts behind SERA makes the process more palatable. Indeed SERA would be a natural way to lead an investigation for those schooled in the IP/PCT model. Some potential changes in CF human factors training may make SERA a logical tool for the future. The CF Central Flying School is in the process of revising their human factors training for all aviation trades (pilots, navigators, weapons systems operators, flight engineers and Air Traffic Controllers). It is likely that the Human Factors in Decision Making (HFDM) courseware, developed by DRDC – Toronto (formerly DCIEM) for the University of Toronto's Professional Pilot and Aviation Management Post Graduate Diploma, will be influential in determining the syllabus. HFDM came out of work, conducted between 1994 and 1998, for the CF's CC-130 Hercules community (Hendy and Ho, 1998). Although the recommendations made at that time were not fully implemented by the CF, some IP/PCT concepts have found their way into various Directorate of Flight Safety programmes, and crew resource management (CRM) courses at the Unit level. In the future there is an expectation that HFDM will be widely taught within the aviation side of the CF. HFDM is formally and rigorously based on IP/PCT and therefore is entirely consistent with SERA. Now there is the potential that material taught in the classroom and re-enforced in operational training, also forms the basis for both operational risk management and accident and incident investigation.

The origin of HFACS can be found in Shappell and Wiegmann's (1997) *Taxonomy of Unsafe Operations*. Yet the migration path from the 1997 taxonomy to HFACS is not clear and if anything moves HFACS away from what theoretical structure was imposed in the original taxonomy. For example, the link with Rasmussen's goal directed 'Intended-Unintended' model of unsafe acts (Reason, 1990, p.207) has been lost in HFACS. HFACS is quite different in detail to the original taxonomy although the hierarchical structure from Reason's work is still evident and indeed has been expanded to include organisational factors. AGA 135 HFACS introduces even more drift. Interestingly SERA combines features from all three theoretical models that Wiegmann and Shappell (1997) consider as candidates for the human factors analysis of post accident data, while also addressing the need to take Reason's latent factors into account. Even here, PCT provides a framework for teasing out the factors associated with the Command, Control, Supervisory, and Organisational aspects and, through HGA, establishes the hierarchical structure that is at the heart of Reason's model.

While the issue of predictive validation remains for both SERA and the risk management tools presented in this report, the theoretical model on which it is based has been partially validated (Hendy, *et al.*, 2001b). Establishing the predictive validity of SERA, or indeed HFACS, is extremely difficult because there is no ground truth to compare the prediction against. The 'true' causes of any accident or incident can rarely be or, in many circumstances, can never be established. At the very least the results need to make sense (face and construct validity). We have come a long way from classifying all human factors issues as 'pilot error' or 'channelised attention' but most likely we have a way to go yet before we can claim that we have a system that "...en-compasses all aspects of human error..." (Shappell and Wiegmann, 2000, p.13)...and really mean 'all' rather than 'most'. HFACS and SERA are steps in the right direction.

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Conclusions

The Systematic Error and Risk Analysis (SERA) process, for investigating the human factors causes of accidents and incidents, is based on a solid theoretical framework provided by the Information Processing (IP) and Perceptual Control Theory (PCT) models. SERA provides a structured process for identifying both active failures and the pre-conditions that led to these failures. In the context of this report, SERA is developed as a tool to help the accident investigator in populating the Canadian Forces' version of the Human Factors Accident Classification System or HFACS. Yet SERA provides its own taxonomy of human factors causes and could stand alone, independent of HFACS, as both an investigation tool and as an accident classification taxonomy. Because of the strong separation between the active failures and pre-conditions that mark the points of intervention for the safety system, SERA can be extended to provide a risk management tool at both the tactical (for operators) and strategic (for managers) levels. A concept for a risk management tool is developed, based on 12 SERA factors at the tactical level and six SERA factors at the strategic level.

SERA gains construct and face validity from the theoretical models on which it is based, but lacks the appeal of a tool that has seen widespread field use such as HFACS. SERA has a formal process for its application that suggests a greater level of complexity than HFACS. This suggestion of complexity is perhaps more imagined than real as the SERA decision ladders are simple to navigate, although they do demand that the investigator is able to answer a series of questions related to the operator's goals, state of knowledge of the world, and their planned actions. While this might seem odious, it is hard to imagine that an understanding of the circumstances of the accident or incident can be obtained in the absence of this information. A proof-of-concept software tool for implementing this process is described.

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Annex A: Definitions for the Points of Failure

In this Annex the points of failure are defined for each layer of the SERA model. These definitions start with the 12 points of active failure and then go on to define the pre-conditions to these failures, both immediate and remote.

Active Failures

1. INTENT FAILURE: The unsafe act resulted from exercising a goal that was inconsistent with Rules and Regulations. This is a failure in **INTENT (VIOLATION)**. Violations do not require that the operator knowingly broke the rules.

Alternatively an **INTENT (NON-VIOLATION)** failure is an unsafe act that resulted from intentionally exercising a goal that, although consistent with Rules and Regulations,

- did not manage or bound the risk (a risky rather than conservative goal),
- was inadequately assessed for risk,
- was not consistent with established operating procedures (this would be an **INTENT - VIOLATION** if the use of SOPs are mandated by the Rules and Regulations), or
- was inconsistent with the state of proficiency, capability or readiness of the individual or the team (e.g., the pilot exceeded current ability).

Goal generation depends on your state of knowledge about the world. For this to be a failure in **INTENT (NON-VIOLATION)** the perception of the situation must be correct.

2. ATTENTION FAILURE: There was a failure to attend to relevant information that was present or accessible. For example:

- Fixation on one aspect of the task captured attention.
- A loss of vigilance or sensitivity for low probability events.
- An intentionally restricted locus of attention…the information was available but the operator did not make the effort to access it
- A breakdown in the time-attention trade-off. Even with an effective time management strategy there would be insufficient time to attend to all the critical information. To know you must attend and to attend you must have time.

3. SENSORY FAILURE: The operator didn't have the physical capabilities at the time of the unsafe act (e.g., visual acuity, hearing) to sense the information required to perform the task. This could be a breakdown in baseline capability, the result of a temporary or correctable condition, or due to physical limitations at the operator interface. For example.

- Inadequate visual acuity due to a failure to wear prescribed corrective lens.
- Visual acuity or hearing has degraded since selection due to age, illness, or injury.
- Temporary auditory threshold shift due to recent noise exposure.
- Presence of glare, low luminance, noise, vibration.

4. KNOWLEDGE (PERCEPTION) FAILURE: The operator didn't have the pre-existing baseline knowledge or skills required to adequately or correctly interpret the situation. The cues received from the world had no meaning or an incomplete meaning to the operator. The operator cannot use the information that is available to interpret the situation even though a knowledgeable operator would be expected to.

5. PERCEPTION FAILURE: All relevant sources of information were attended to but an incorrect perception was formed due to ambiguous or illusory information, or due to processing biases that shape our perceptions and filter the available information. This is a breakdown in forming a 'picture' of what is happening, and is NOT a limitation due to sensory capability nor a breakdown in prerequisite perceptual task knowledge.

6. COMMUNICATION/INFORMATION FAILURE: A failure in communication or information exchange between machine (display) and human, or human and human. The operator was did not receive relevant information, or was passed incorrect information. This is a breakdown in the information link between human and human or between human and machine or display.

7. TIME MANAGEMENT FAILURE: A failure to use appropriate and effective time management strategies, including: incorrect or inappropriate prioritisation of attention, failure to delegate, postpone, shed tasks, failure to simplify the task, failure to take control of the timeline of the activity, or a failure to pre-plan or bring tasks forward.

8. KNOWLEDGE (DECISION) FAILURE: The operator didn't have the pre-existing baseline knowledge or skills required to form an appropriate or correct response to the situation. The operator doesn't know the correct or appropriate response for this situation or can't demonstrate an adequate technique. This is a failure in knowing what to do rather than a failure in implementing the response.

9. ABILITY TO RESPOND FAILURE: Didn't have the physical capabilities (e.g., strength, reach, reaction time, vocal effort) to make the response required to perform the task. This could be a breakdown in baseline physical capability (not knowledge), could be due to a temporary or correctable condition, or could be due to physical limitations at the operator interface. For example.

- Insufficient lifting strength.
- Noise, vibration, or loss of power assistance.
- Muscle pulls, strains or other injuries that limit the range of motion of force exerted.

10. ACTION SELECTION FAILURE: A failure in the decision process due to shortcomings in action selection, rather than a misunderstanding or misperception of the situation. These are failures to formulate the right plan to achieve the goal, rather than a failure to carry out the plan. For example:

- An incorrect or inadequate procedure was implemented as intended. A correct or adequate response does exist in memory but was not selected. This includes an inappropriate 'no action.' This could be due to:
    - Failures in knowledge-based reasoning due to working memory limitations, or processing biases.

  - Failures in rule-based (IF 'A' then 'B') reasoning where once the IF part of the situation is recognised the THEN part of a previously used rule is inappropriately applied. This typically occurs when exceptions to rules are not recognised.
  - Failure to the use an appropriate technique, but only if the operator could demonstrate a correct or adequate technique under other circumstances (if they can't the failure is in Knowledge - Decision).

- There is insufficient time to choose a correct or adequate course of action from memory even though it does exist or would likely be derived if more time were available. There is no time to generate alternatives and test them mentally for their appropriateness.
- Freezing: the operator does nothing to correct a recognised problem due to a perceived inability to change the situation; this doesn't include a planned 'no action', forgetting, or a lack of response because there is no time to formulate one.

11. SLIPS, LAPSES AND MODE ERRORS: The response was not implemented as intended. This is a failure in action execution rather than action selection…what was done was not what was intended. The wrong sequence or plan was triggered. These types of errors include:

- Slips, misses and bungles: occurs when the intended behaviour is 'captured' by a similar well-practised behaviour (e.g., operating the gear lever instead of the flap lever). These are failures in skill-based behaviour. Slips may occur when: the intended action involves a slight departure from the routine; some characteristics of the stimulus of the action sequence are related to the inappropriate but more frequent action; the action is relatively automated (skill-based behaviour) and is therefore not closely monitored (feedback). Generally feedback detects slips and misses as the deviation from intended action is often easily detected.
- Lapses: a planned response was not actioned at the appropriate time, missed a check list item or a step in a procedure, left a tool in the work area, not torquing a nut at the end of an assembly procedure, bumping into something or inadvertently activating a control. Lapses are what might be called forgetfulness (failures in prospective memory), often precipitated by an interruption. Lapses are often seen in maintenance and installation procedures.
- Mode errors: performing an action that is inappropriate in the current mode but would be appropriate in another mode. Generally these errors occur when the operator forgets which mode is selected or forgets that the action they are about to perform gives different than expected results in the current mode.

Operators are more likely to monitor their actions than the results of their actions. Hence slips are often self corrected while lapses, mode errors and mistakes often go undetected for long periods of time.

12. FEEDBACK FAILURE: Our internal models (where things are in space, vehicle dynamics, how things work, etc.) of the world are often imprecise but as long as error-correcting feedback is maintained we can generally expect to achieve the goal. If feedback is not present, such as when attention is shifted prematurely, there is a failure in error correction. Feedback breaks down whenever a situation occurs where no one or nothing (humans or machines) is monitoring to 'see' that the goal has been achieved. This includes failure in backing-up, crosschecking or monitoring to ensure goal achievement. Feedback should be maintained at the individual (monitoring, checking), team (crosschecking, supervision, backing up) and organizational level (Command and Control, organization health monitoring, oversight). Was feedback maintained or did the behaviour go 'open loop'?

Pre-conditions to Active Failures

The immediate pre-conditions describe the condition of the:

- Personnel,
- Task, and
- Working environment.

Condition of the Personnel

The condition of the personnel is further broken down and defined by the following seven states. These seven states describe the condition of the individuals, working both individually and as a team or group.

- Physiological,
- Psychological,
- Social,
- Physical capability,
- Personnel readiness,
- Training and selection, and
- Qualification and authorization;

Together these conditions impact all components of the IP/PCT model and hence the human decision maker. The personnel factors are broken down as follows.

PHYSIOLOGICAL: Physiological states that are associated with impaired performance include:

- Drowsiness.
- Medical illness.
- Pharmacological and toxicological effects.
- Acceleration effects.
- Circadian and time of day effects.
- Decompression sickness.
- Intoxication.
- Hang over.
- Hypoxia.
- Trapped gas effect.

- G-Induced Loss of Consciousness.
- Physiological Incapacitation.
- Physical Fatigue.
- Other Physiological Impairments.

PSYCHOLOGICAL: psychological states, attitudes, traits, and processing biases shape the goals we set, the way we interpret or perceive information, and the actions we form. Certain states can contribute to the likelihood of an active failure.

- Complacency: "…it can't happen to us", "…it'll be alright", "…no need to worry."
- Resignation: "…there's nothing we can do." The operators resigned themselves to the outcome and stopped trying to respond.
- Motivation can be too high leading to risky behaviour, or too low reducing the amount of effort put into the task.
    - Excessive motivation to get the job done (e.g., Get-home-itis, excessive 'can-do' attitude) can lead operators into situations that are beyond their capabilities or the capabilities of there crews under the circumstances (level of training, fatigue, etc.) Risk management can break down.
    - Low motivation can lead to reduced locus of attention (what information you are prepared to seek out), the willingness to consider alternative courses of action, delays in responses, breakdown in monitoring, cross checking and all forms of feedback, and willingness to share information in a team environment. Generally low motivation translates into a lack of enthusiasm for the task.
- Morale: leading to a lack of motivation to work the problem.
- Macho: – showing off, trying to impress often leads to risky choices.
- Anti-authoritarian: reflects the attitude "…rules are just made to be broken…they don't apply to us…"
- Boredom: boredom translates into a state of low motivation and commitment to the task.
- Distraction and Life Stress: factors external to the primary task that compete for attention (prolonged extraneous conversation, financial concerns, domestic problems, forthcoming exams or a meeting, a purchase etc.). While your attention is turned to these external events it is not available to apply to the primary task. These are pervading factors that act over extended periods of time during the performance of the task. They are not momentary distracters such as an alarm, a loud noise, or a brief flash in the visual field.
- Mental fatigue: weariness felt after long periods of intense mental activity and sustained concentration that affects the ability to attend to the task at hand.
- Attentional information Processing Biases: attentional information processing biases shape what we attend to (they are present in the absence of time pressure but become

more dominant as time pressure increases). They are not *brain failures* but represent time efficient strategies for human problem solving. However, they can let us down as they filter the available information. Here are some examples:

  - Salience - we are hard wired to attend to and place higher emphasis on information associated with loud sounds, bright lights, motion and position in our visual fields (in our central field, at the top of displays etc.). These are momentary distracters that briefly capture attention.
  - Confirmation bias - the tendency to seek out information that confirms our initial assessment rather than information that is contrary.

- Perceptual information processing biases shape how we weight and assimilate information (they are present in the absence of time pressure but become more dominant as time pressure increases). They are not *brain failures* but represent time efficient strategies for human problem solving. However, they can let us down as they filter the available information. Here are some examples:
  - Availability: the probability of events is evaluated by the ease with which relevant instances come to mind. In general, frequent events are easier to recall or imagine than infrequent ones.
  - Ignoring prior probabilities: humans tend to ignore the base rate or underlying probabilities of a particular situation (e.g., fog in the region at this time of year, excessive downdrafts with the wind from a particular quarter).
  - Intuitive statistician: humans tend to overestimate the likelihood of occurrence of low probability events, and underestimate the occurrence of high probability events.
  - Anchoring: the tendency for the order in which information is gathered to guide (or anchor) the interpretation of the situation. If the information is simple we tend to weight the information received first most heavily, if it is complex we tend to weight the most recently received information most heavily.
  - As-if bias: people tend to weight all data as equally important to the decision process even if they are not.
  - Representativeness heuristic: the tendency to assume that a situation that has similar characteristics to something you have experienced before, is indeed the same.
  - Expectation: our perceptions are shaped by what we expect or do not expect (e.g., if you are cleared to land [expectation is that the runway is clear], you would not expect to see another aircraft occupying the runway)
- Decision biases effect action selection (these are present in the absence of time pressure but become more dominant as time pressure increases). They are not *brain failures* but represent time efficient strategies for human problem solving. However, they can let us down as they filter the available information. Here are some examples:

    - Availability: the tendency to use the response that is most familiar or has been used recently.
    - Over confidence: people in general are more confident of their chosen course of action than is reasonable given the uncertainty in the decision-making environment. There is the potential to close off the search for answers before all available evidence can be collected because of overconfidence.
    - First-to-fit: the selection of the first course of action that seems appropriate. Operators often do not explore a complete or even a large set of options.
    - Sunk cost bias: a tendency to put more resources into a process that you already have an investment in.
    - Strategy persistence: a tendency to keep doing what you have been doing even though an outside observer can see that it is no longer appropriate (pressing on).
- Other Psychological States.

SOCIAL: Factors that determine the effectiveness of how groups and teams interact. For example:

- Trans-cockpit Authority Gradient: the perceived willingness of the Aircraft Commander to use both Leadership and Command styles to set the direction taken by the aircraft crew.
    - A steep gradient, biased towards the Aircraft Commander, occurs when the AC constantly achieves team goals by using Command authority rather than Leadership or Personal authority. This reinforces the command structure but jeopardises the free flow of information between crewmembers.
    - A neutral gradient exists when the AC consistently achieves team goals by the use of Personal rather than Command authority, and encourages contributions from all crewmembers. Command authority is reserved for those times when critical decisions must be made against high time constraints. This creates a strong environment for team working.
    - A steep gradient, biased towards the Co-pilot or another crewmember, exists when the AC fails to Command when it is appropriate and the Leadership role passes to another crewmember with strong personal authority. This jeopardises the command structure and the AC's role within the cockpit team.
- Rank gradient: the perceived willingness to use Leadership or Command styles to set the direction taken by the team.
    - A steep gradient, biased towards the senior person, occurs when team goals are constantly achieved using Command authority rather than Leadership or Personal authority. Note that the senior person may or may not be the designated team Commander or Leader, in the sense of the position rather than the style (e.g., in an aircraft cockpit). This reinforces the command structure but jeopardises the free flow of information between team members.
    - A neutral gradient exists when the senior person consistently achieves team goals by the use of Personal rather than Command authority, and encourages

contributions from all team members. Command authority is reserved for those times when critical decisions must be made against high time constraints. This creates a strong environment for team working.

  - A steep gradient, biased towards more junior team members, exists when the senior person fails to Command when it is appropriate and the Leadership role passes to other team members with strong personal authorities. This potentially jeopardises the command structure and the senior person's role within the team.

- Peer pressure: one may believe that acceptance by the peer group depends on adopting the group's attitudes and norms. Behaviours will be shaped by a desire to act in accordance with these perceived attitudes and norms.
- Leadership: to *lead* is to use your personal authority to influence the direction the team follows (compared to Command where your legitimate or legal authority is used to the same end). People follow leaders willingly (one does not have to be willing to be commanded) without threat of coercion. Leadership is established by behaviours that build trust and respect. The strength of leadership (and indeed Command) is judged by how well the Leader forms intent, communicates the intent to the team, obtains the buy-in of the team members, and controls the pace of the task so that the team can follow.
- Commitment to the team: this defines the likelihood that team members will display effective followership and situational leadership.
- Assertiveness: assertiveness describes the force and conviction with which information is conveyed to another team member. Assertiveness should be situationally appropriate. When the safety of the operation is at jeopardy, the highest level of assertiveness is called for.
- Receptiveness: describes the readiness of any team member to accept input from all sources.
- Cohesiveness: the extent to which the team agrees on the common goals and the process of achieving them.
- Group think: a complex concept leading to behaviours of self censorship, and illusions of unanimity where no dissenting information is offered that threatens the position taken by the group or team.
- Social loafing: one or more team members do not actively contribute to the common goals. They rely on other team members to get the job done.
- Other Social Factors

PHYSICAL CAPABILITY: Factors that determine the capability (physical not cognitive) to sense information and implement the intended action or behaviour. These include:

- Body size.
- Strength.
- Flexibility or range of motion.

- Dexterity.
- Visual acuity.
- Colour vision.
- Field of view.
- Hearing.
- Localization of sound.
- Reach.
- View.
- Other Physical Capability Limitations.

PERSONAL READINESS: An operator's personal obligation to be ready physiologically, psychologically, physically and mentally to perform the task. If an operator is not ready to perform the task they must let the team or their supervisor know. Personal readiness factors refer to the operator's actions prior to and leading up to the performance of the task. They are what the operator did or did not do in preparing for the performance of the task. For example:

- Alcohol consumption while on duty or immediately prior to duty.
- Inadequate rest.
- Is in possession of the required personal aids to perform the task (corrective lens, hearing protection, personal equipment ensembles)
- Is in possession of the required personal tools and equipment for the task.
- Use of prescribed drugs or medication that affects physiological or psychological states.
- Use of self-medication (e.g., anti histamines that induce drowsiness) that affects physiological or psychological states.
- Recent excessive physical exertion.
- Carrying injuries that effect range of motion and the ability to exert force.
- Has maintained personal skills and knowledge required for the job.
- Other Personal Readiness Factors.

SELECTION AND TRAINING: Selection and training deal with the skills required to do the job not the legal authority.

- Selection: the operator lacked the basic abilities (aptitude, vision, hearing, language, etc.) that would allow the situation to be correctly interpreted or would allow an adequate response to be formed.
- Training: the operator had the basic abilities (vision, hearing, language, etc.) but lacked the knowledge required to correctly assess the situation or would allow an adequate response to be formed.

  - Baseline knowledge: prerequisite or underlying knowledge. Knowledge that is fundamental to doing the job. Knowledge learnt in basic training (e.g., aircraft radio aids and their function in navigation).
  - Task knowledge: specific knowledge that is required to perform the task (e.g., how to fly a back course ILS).
  - Aircraft Knowledge: knowledge specific to the aircraft type and its systems (e.g., how to set up the FMS and the correct approach speeds for landing and gear/flap deployment).

- Currency: skills and knowledge have degraded over time and have not been refreshed.

QUALIFICATION AND AUTHORIZATION: Qualification and Authorization deal with the legal pre-requisites for performing certain activities (qualified on type, qualified to handle hazardous materials, authorized to fly the mission etc.) rather than the ability or capability to carry out the task.

- Qualification: the operator was not qualified to conduct the activity.

- Authorization: the operator was not authorised to conduct this activity.

While unqualified or unauthorised personnel may lack either capability or ability it doesn't necessarily follow. The active failures will directly implicate the ability and capability of the personnel to carry out the activity (e.g., capability and knowledge failures are likely when unqualified or unauthorised people are used to perform the task) independently of the state of qualification or authorisation of the personnel.

Condition of the task

The condition of the task is described by two factors.

TIME PRESSURE: The tempo of the task is excessive. There is little or no time to rest or re-group, "…there is no time to think." Operators are paced by the task and have little scope to actively manage the timeline. Options for timeline management are few, if at all. Responses are required immediately the stimulus appears. Response delays are unacceptable.

The IP model describes the breakdown of the human information processing system under excessive levels of time pressure, but there are other situations, not described by the IP model, where performance is degraded despite low task tempo. For example, activities where events are insufficiently frequent to maintain physiological activation and psychological arousal levels will promote a state of sleep, with the possibility that what would normally be an easily detectable event is missed (an isolation cell is an extreme example of this type of situation).

Vigilance tasks are special cases of low task tempo situations. Vigilance tasks are special cases because of:

- the requirement for sustained attention over extended periods of time and rapid response to the stimuli when it does appear (hence they may not be perceived as low workload situations),

- low probability events, and

- events of low detectability.

Although fundamentally different, in all cases a failure in attention might be expected.

OBJECTIVES: The objectives set for the task generate the tactical and strategic goals for the operators performing the task and define the nature of the task. Are the objectives:

- consistent with the actual capabilities and/or experience levels of all operators who are qualified and authorised to do the job?
- appropriate for the approved mission?
- clearly understood or uncertain?

Do the objectives:

- involve high risk with low benefit?

Working conditions

The following factors describe the working conditions.

EQUIPMENT (TOOLS OF THE TRADE): These factors describe the interfaces with which the operator(s) is attempting to carry out the task. This includes: controls, displays, panels, transparencies, knobs, dials, levers, connectors, life support and protective equipment, tools, test rigs, information sources including documentation and manuals etc. Is the equipment:

- Unsafe/Hazardous?
- Unreliable/Faulty?
- Difficult to operate?
- Uncontrollable?
- Available?
- Inappropriate for task?
- Miss calibrated?
- Correctly documented?
- Designed in accordance with good human engineering principles?
- Other Equipment Factors?

WORKSPACE: These factors describe the physical arrangement and layout of the workspace itself, including:

- Physical constraints that limit movement, or limit the use of tools and equipment.
- Displays or critical information that are not visible, obstructed or partially visible.
- Controls or components totally or partially inaccessible.
- Cockpit layout.
- Seating.

- Other Workspace Factors.

ENVIRONMENT: These factors describe the environment in which the activity takes place, including:

- Lighting (inadequate natural/artificial light, dusk/night time)
- Weather/exposure (temperature, precipitation, wind, cloud cover etc.)
- Environmental hazards (radiation, ice, water, noise, housekeeping, cleanliness, hazardous /toxic substances)
- Other Environmental Factors.

Failures in Command, Control and Supervision

Command, Control and Supervision are described in the following terms.

FORMING INTENT: The objectives of the task, and lines of responsibility, were not clearly formulated by Managers and Supervisors. This is failure in the formation rather than the communication of the strategic objectives for the mission.

Were the high level goals set by Managers and Supervisors:

- contradictory;
- ambiguous;
- in violation of SOPs, Rules and Regulations; or
- based on unrealistic expectations?

COMMUNICATION OF INTENT: The objectives of the task and lines of responsibility were not clearly communicated by Managers or Supervisors. This is a failure in communicating the intent to those that are to carry out the objectives. The problem is in communicating the intent, not in forming the intent. Were the objectives, as stated, ambiguous or contradictory ("…achieve the best performance you can, spend the least amount of money") or was the intent poorly communicated (generally ambiguous goals can not be communicated clearly, but sometimes the communication of a clearly defined goal will fail also)?

MONITORING AND SUPERVISION: Monitoring or supervisory activities are missing, delayed or were otherwise inadequate to provide error-correcting feedback ensuring successful task or mission completion.

Organizational failures

Organisational influences involve the following factors.

MISSION: Is the mission clearly defined, approved, and within the capability of the organization? The stated mission should be consistent with the resources available. Note that in a new or changing organization the mission statement usually comes first and then the required resources are defined and provided…in a mature organization new missions may be conceived for an organization that has a fixed resource base. This is a 'chicken and egg' issue…there is always a trade-off between the acceptance of the mission and the availability of resources. The point of failure depends on the constraints. If the resources are fixed then the mission statement must be matched to the assets available. If the statement of the scope of the mission exceeds the resources, then the failure is in the mission statement not in the provision of the resources.

PROVISION OF RESOURCES: This refers to the management, allocation, and maintenance of organizational resources, such as:

- **Human** - the term 'human' refers to operators, staff, support and maintenance personnel. Personnel issues that directly influence safety include the organization's obligation and ability to select capable people, train them to criteria performance, and staff/man units to a level that is consistent with the mission requirements.
- **Equipment/facilities** - Equipment/Facility refers to issues related to equipment design, including the purchasing of equipment that is suitable for the role and failures to correct known design flaws. Management should ensure that human factors engineering principles are known and utilised in procurement, and that appropriate specifications for equipment, workspace design and the working environment are identified and met.
- **Monetary** - monetary issues refer to the management of non-human resources, primarily monetary resources. Are funding levels adequate to provide proper and safe equipment, and appropriate numbers of trained personnel?

The resources available should be consistent with achieving the mission. Note that in a new or changing organization the mission statement usually comes first and then the required resources are defined and provided…in a mature organization new missions may be conceived for an organization that has a fixed resource base. This is a 'chicken and egg' issue…there is always a trade-off between the acceptance of the mission and the availability of resources. The point of failure depends on the constraints. If the mission is stated and the organization has the freedom to increase its resources to match the requirements of the mission, but fails to identify this need or follow through on an identified shortfall, then the failure is in the provision of resources.

RULES AND REGULATIONS: Rules and Regulations have a special place within an organization's processes. Rules and Regulations, which may be imposed by an external body, set the constraints and establish the legal requirements within which the operational mission has to be accomplished (e.g., Rules of Engagement).

Not acting in accordance with Rules and Regulations will generally invite disciplinary action. Are the Rules and Regulations consistent with the mission requirements? Can you do the job safely within the constraints imposed by the Rules, Regulations? Do the Rules and Regulations establish sufficient safeguards for the operation?

ORGANIZATIONAL PROCESS: *Organizational process* refers to the formal processes by which things are supposed to be accomplished in the organization. Three factors are included in this area – operations, procedures, and managing change.

- **Operations** - 'operations' refers to processes established by management that determine the characteristics or conditions of work. These include the use of production quotas and incentive systems to motivate workers, schedules to maintain the usage of plant or maintain the health and well being of the workers etc. When set up inappropriately, these processes can establish working conditions that are detrimental to safety.

- **Procedures** – procedures are the official or formal statements as to how the job is to be done. Examples include performance standards, objectives, documentation, SOPs, instructions about procedures, etc. Poor procedures can negatively impact supervision, performance, and safety.
- **Managing change** – these are processes in place for initiating and managing change in the organization in response to the information provided by oversight.

ORGANIZATIONAL CLIMATE: *Organizational climate* refers to organization variables that shape worker attitudes and make certain behaviours more likely to emerge. The organizational climate reflects the values that the organization is actually pursuing (these are not necessarily the stated values). In general, organizational climate describes the prevailing atmosphere or environment within the organization. It is defined as "…situationally-based consistencies in the organization's treatment of individuals" (from Jones, 1988, as quoted by Shappell and Wiegmann, 2000, p11). Organizational structure, policies, and culture are elements that affect the climate.

- **Structure** – 'structure' refers to the formal component of the organization, its 'form and shape.' An organization's structure is reflected in the chain-of-command, delegation of authority and responsibility, communication channels, and formal accountability for actions. Organizations with maladaptive structures will be more prone to accidents.
- **Policies** – policies refer to a course or method of action that guides present and future decisions. Policies may refer to hiring and firing, promotion, retention, raises, sick leave, attitudes to drugs and alcohol, overtime, accident investigations, use of safety equipment, etc. When these policies are ill defined, adversarial, or conflicting, safety may be reduced.
- **Culture** - culture includes the acceptance of unspoken or unofficial rules, and customs of an organization "…the way things really work around here." In this case the actual process does not follow the formally set down process of the organization. Other issues related to culture included organizational justice, psychological contracts, organizational citizenship behaviour, esprit de corps, and union/management relations.

All these issues affect manager and worker attitudes about safety, adherence to guidelines and SOPs, and the value of a safe working environment.

OVERSIGHT - oversight refers to management's procedures for monitoring and checking resources, climate, and processes to ensure a safe and productive work environment. Issues here relate to the existence of methods for organizational self-study, risk management, and the establishment and use of safety programs. Oversight provides the error correcting feedback for identifying and correcting (with a process for managing change) systemic deficiencies in the **MISSION**, the **PROVISION OF RESOURCES**, the **RULES AND REGULATIONS**, the **ORGANIZATIONAL PROCESS**, and the **ORGANIZATIONAL CLIMATE**.

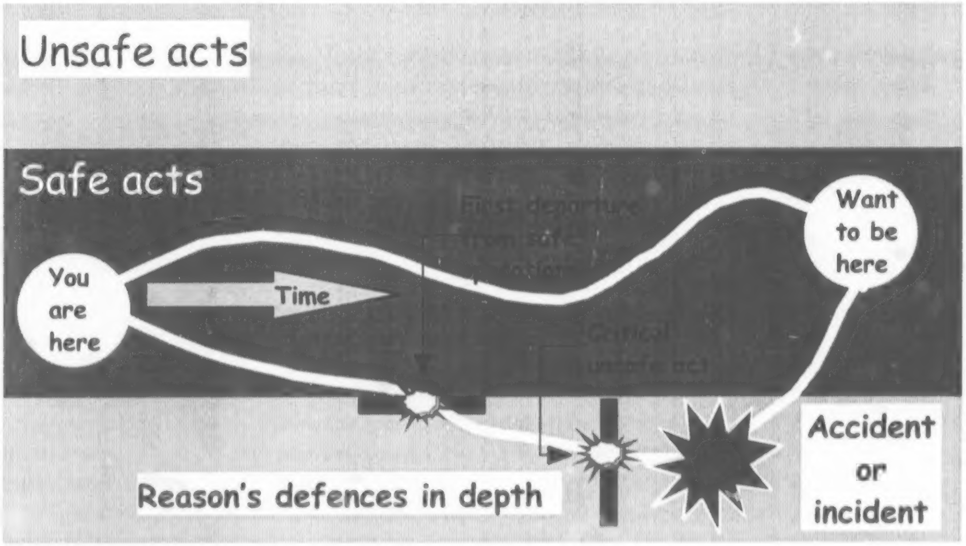
Annex B: Implementing a SERA Analysis

Implementing a SERA analysis involves the following five Steps.

STEP 1 (Identify the unsafe act or unsafe condition)

WHAT IS AN UNSAFE ACT? An act is something that someone has done…it is observable…it is the outcome of a decision (e.g., "…the pilot initiated a roll and pull-through manoeuvre from 3000ftAGL). You might have risky intentions, but until such time as you take action there is no unsafe act. A risky goal is not an unsafe act until something is done about it, although announcing your intent to another party may be considered an unsafe act if there is an expectation that the intent will be carried out.

WHAT IS AN UNSAFE CONDITION? A condition is some state of the world. It also is observable (e.g., "…the aircraft descended below the MDA without the runway in sight"). Here you are describing, "…what was" rather than "…what was done."



DEPARTURE FROM SAFE OPERATION. Identify the first point in the timeline where there is a departure from safe operation. Describe the unsafe act or unsafe condition that marks this point. You need to be able to trace the path from this unsafe act to the final outcome. The unsafe act is on the accident or incident trajectory if its removal or modification would have prevented the accident or incident. State the facts of the unsafe act or condition; do not attribute cause at this stage. The most critical unsafe act or condition is that from which there is only one trajectory…the one that led directly to the accident or incident. Up until that critical act or condition, there were always options. Once the critical decision has been made there is no way back. The accident or incident crew may have committed several unsafe acts or there may have been several unsafe conditions that you wish to analyse, in which case you would follow the process for each of these unsafe acts or conditions.

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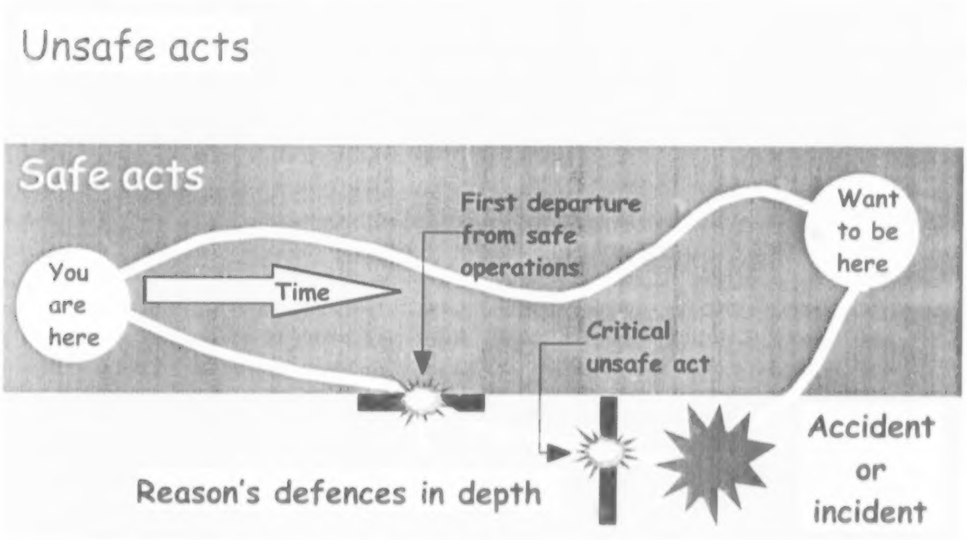

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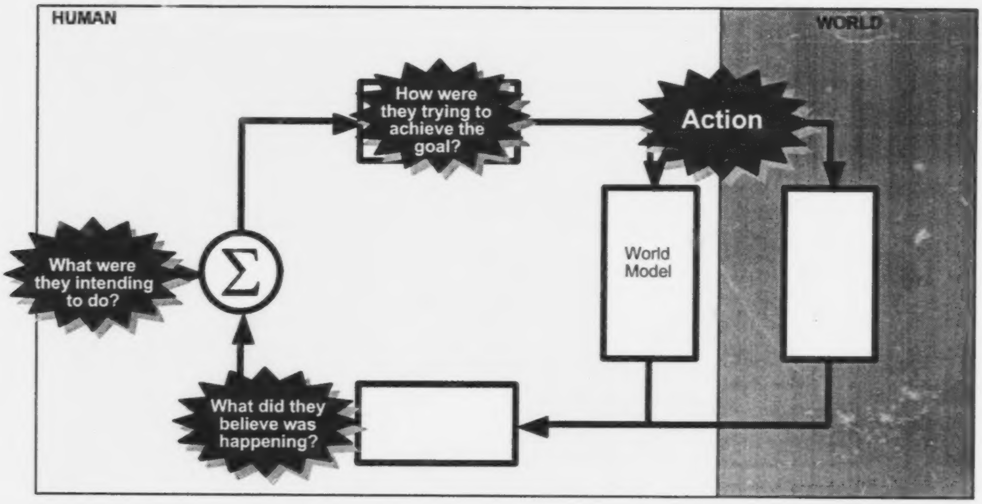
WHO DO YOU START WITH? Start with the operators or crews who were **directly** involved in the unsafe act or unsafe condition. These are the operators or crews who were controlling the variable(s) that went out of the safe or acceptable range(s) (e.g., altitude, airspeed, aircraft position with respect to airspace restrictions, torque on a nut, installation of a part). Other players and latent factors or pre-conditions, both human and machine, will be identified as you go through the SERA process. While these other players and pre-conditions may have set the scene for the accident or incident, they were not directly involved in the unsafe act or condition. You are trying to find out why these particular operators or crews were involved in an accident or incident. For other operators or crews, under the same pre-conditions, the outcome may have been different.

STEP 2 (Ask three questions)

For each unsafe act, ask three questions of the operators or crewmembers (do this before proceeding to the next steps):

GOAL:	"What was the operator or crew member trying to achieve…what was the intent or goal(s) that led to the unsafe act?"
PERCEPTION:	"What did the operator or crewmember believe was the state of the world with respect to the goal(s)?"
ACTION:	"How was the operator or crewmember trying to achieve the goal(s)?"


HUMAN
WORLD
How were they trying to achieve the goal?
Action
World Model
What were they intending to do?
Σ
What did they believe was happening?

Each of these statements should be as objective as the information allows. Stick to the facts; do not colour the descriptions with what might be the pre-conditions or directly refer to what might be active failures. Do not pre-judge the situation. These statements should all be at the same level of description.

The **GOAL** we are concerned with is the one that led directly to the unsafe act or unsafe condition we are analysing, and will be described at the same level as the unsafe act or condition. Defining the **GOAL** is always critical to knowing why someone did something. It is the first line of defence in risk management and sets the scene for the observed action. The goals we set always involve an assessment of the risk, at least some level (of course this is not to say that the assessment was adequate or correct).

The description of the **PERCEPTION** should include only those factors that are relevant to the stated goal. This will include the perceptual information required to judge the current state of the world with respect to the goal ("…are we there yet…has my goal been achieved?"), as well as the information against which the appropriateness of the goal in question is judged ("…does this goal satisfy my higher level goals such as level of risk, or contribution to the mission?"). We also draw on information from our internal knowledge states in forming the overall perception (past experience, training, knowledge of how things work…drawing on our internal world model) as well as the sensory information currently stimulating our receptors.

The **ACTION** statement should include only those actions that are intended to achieve the stated **GOAL**.

Identify the Active Failures

Start the analysis with one of these questions (usually you would start with the **PERCEPTION** so you can see the context for the goals that were set, but you might start directly with the **GOAL** or even the **ACTION** if that is the only direct evidence you have); follow the process down to the active failure(s) by asking a series of questions related to each decision point in the process. Do this for **STEPS 3** to **5**.

If the **GOAL** is stated at a high level (e.g., "…the Captain intended to fly the mission as originally planned…") then the **PERCEPTION** and **ACTION** statements will be at the same level of the **GOAL**. Hence, you might identify several active failures in one or more of the decision ladders for what are essentially sub-goals of this higher-level goal. That's OK.

If the **GOAL** is very specific (e.g., "…the pilot intended to level at 15000ft…") you may identify just a single point of failure in only one ladder (**PERCEPTION**: attentional failure – did not see the altimeter advance through 15000ft).

Identify the Pre-conditions

Once you have identified the active failure(s), look for pre-conditions that were acting to make the active failure(s) more likely. A set of most likely pre-conditions has been associated with each active failure in the decision ladders. Use these as a guide but be prepared to identify others. For a condition to be a pre-condition of the active failure ask yourself "…would the outcome have been different if this condition was absent or different?" You should find at least one pre-condition to every active failure but you may find many. Note that the points of intervention for reducing the likelihood that the active failure will occur again are defined by the pre-conditions, not the active failures. In SERA, the active failures are due to human information processing limitations that are basically fixed properties of the humans.

In the process of identifying the pre-conditions to the unsafe act you might for example find a case where a supervisor or a unit initiated a risky mission, or violated Rules, Regulations, or SOPs. These might be seen as unsafe acts in their own right and you may wish to analyse them using the full SERA process.

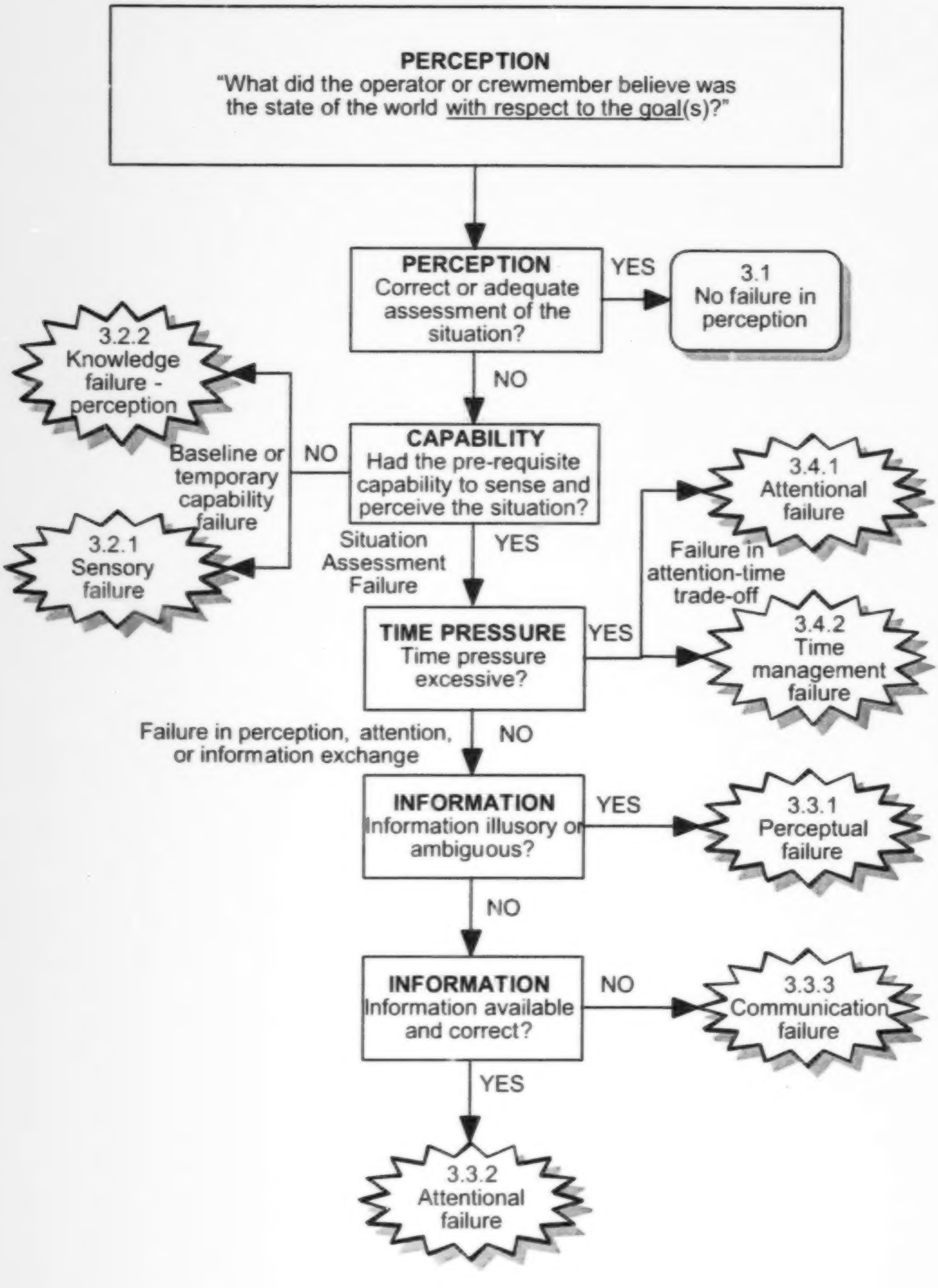
In other words, the unsafe act of a supervisor was identified as a pre-condition to the unsafe act of the accident crew, The supervisor's unsafe act might then be fully analysed to identify the supervisor's active failures and pre-conditions to these failures, using the three questions:

GOAL:	"What was the supervisor trying to achieve?"
PERCEPTION:	"What did the supervisor believe was happening?"
ACTION:	"How was the supervisor trying to achieve the goal(s)?"

Many pre-conditions might fit into this class and be candidates for detailed analysis. For example, the decision to buy a particular aircraft that may not be fully suited to the mission, the decision to implement a new work-rest schedule, or the decision to limit the amount of NVG training in a Squadron. These might all be found to be pre-conditions to the unsafe act that precipitated the accident or incident that is under investigation. Now you want to find out why these emergent unsafe acts occurred. Note that these pre-conditions remained latent or hidden until the accident occurred…they emerged as a result of the investigation.

Now you are ready to proceed with **STEP 3**.

STEP 3 (What was the perception?)


PERCEPTION
"What did the operator or crewmember believe was the state of the world with respect to the goal(s)?"
PERCEPTION
Correct or adequate assessment of the situation?
YES
3.1
No failure in perception
NO
3.2.2
Knowledge failure - perception
Baseline or temporary capability failure
NO
CAPABILITY
Had the pre-requisite capability to sense and perceive the situation?
3.2.1
Sensory failure
Situation Assessment Failure
YES
3.4.1
Attentional failure
Failure in attention-time trade-off
TIME PRESSURE
Time pressure excessive?
YES
3.4.2
Time management failure
Failure in perception, attention, or information exchange
NO
INFORMATION
Information illusory or ambiguous?
YES
3.3.1
Perceptual failure
NO
INFORMATION
Information available and correct?
NO
3.3.3
Communication failure
YES
3.3.2
Attentional failure

In the following text, the paragraph numbers match the numbers associated with each point of active failure.

For the **PERCEPTION**, ask if the operator or crew had a correct or adequate assessment of the situation. In other words, did the crew's assessment of the situation match the actual situation?

3.1 NO FAILURE IN PERCEPTION. If the answer is YES, you would exit this branch with "no failure of perception" and move on to what the crew was trying to achieve (**GOAL**) or how they were going about it (**ACTION**).

But if the crew's **PERCEPTION** was incorrect or didn't provide an adequate assessment of the situation (in other words the crew's assessment of the situation did NOT match the actual situation), go on to ask the following.

Did the operator or crew had the pre-requisite capability, knowledge or skills required to sense and perceive the situation?

If the answer to the question "…did the operator or crew had the pre-requisite capability, knowledge or skills required to sense and perceive the situation?" is NO, then the failures are either in **SENSORY** capability or in **KNOWLEDGE — PERCEPTION** capability.

3.2.1 SENSORY FAILURE: Before you can correctly perceive the situation, you have to be able to sense the incoming visual, auditory, tactile and olfactory cues coming from the environment. Did the operator or crew have the visual acuity to sense the visual signal, the sensitivity of hearing to detect the sound signal, the tactile feel to sense the force applied the part, etc? If not, this is a SENSORY failure.

> **PRE-CONDITIONS** for a **SENSORY** failure: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.
>
> > **PHYSICAL CAPABILITY**: the crew or crewmember either permanently or temporarily lacked the physical capability to sense the information.
> >
> > **SELECTION**: the selection system failed to screen out personnel lacking the underlying physical capabilities (vision, hearing, tactile, etc.) to sense the information required to perform the task.
> >
> > **PHYSIOLOGICAL**: Various physiological factors can impair sensory capabilities (medical illness, pharmacological and toxicological effects, acceleration effects etc.)
> >
> > **PERSONAL READINESS**: certain personal readiness factors may contribute to an inability to sense the incoming information (e.g., not wearing corrective lens, not wearing regulation hearing protection).
> >
> > **OBJECTIVES**: are the task objectives consistent with the physical capabilities of personnel who are expected to carry out the activities or the performance of the equipment provided for the task?
> >
> > **EQUIPMENT**: various items of personal equipment may interfere with the ability to sense various cues from the world (tinted visors, hearing protection etc.).

ENVIRONMENT: various environmental factors can result in a temporary inability to sense the information (e.g., vibration, glare, and noise).

MONITORING AND SUPERVISION: was the lack of capability previously observed and action taken to re-assign the personnel?

ORGANIZATIONAL PROCESS: the organization must ensure that relevant selection standards have been established, and that personnel deemed 'qualified' have been selected against those standards.

OVERSIGHT: were systemic deficiencies in selection standards known and was corrective action taken?

3.2.2 KNOWLEDGE (PERCEPTION) FAILURE: We need experience, training, or previous exposure to certain complex environments in order to know what it is we are looking at, touching, hearing etc. An obvious example is the need for a specific underlying knowledge to understand a foreign language. A person that hasn't flown may not be able to form a correct perception of aircraft attitude and location in space by observing a conventional aircraft instrumentation display. In other words, they lack the knowledge necessary to form a correct perception. Does the operator or crew have the necessary underlying knowledge to perceive the situation? If not, this is a failure in **KNOWLEDGE – PERCEPTION**.

PRE-CONDITIONS for a **KNOWLEDGE – PERCEPTION** failure: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

SELECTION: the selection system failed to screen out personnel lacking the basic aptitudes (perceptual, language, mathematical, etc.) that would allow the situation to be correctly perceived.

TRAINING: the crew or crewmember possessed the aptitudes (perceptual, language, mathematical, etc.) and physical capabilities but lacked the baseline, task or system specific knowledge required to correctly assess the situation.

CURRENCY: the operator was once trained to standard but skills have degraded over time and have not been refreshed.

QUALIFICATION AND AUTHORIZATION: the crew was not qualified and/or authorised to conduct the activity.

OBJECTIVES: are the task objectives consistent with the knowledge of personnel who are expected to carry out the activities?

FORMING INTENT: were the requirements of the mission appropriate for the organization.

COMMUNICATING INTENT: was the intent of the tasking understood.

MONITORING AND SUPERVISION: in authorising an activity, supervisors have a responsibility to ensure that operators are qualified, current and have the requisite knowledge to carry out the task.

PROVISION OF RESOURCES: were adequate human resources available in terms of properly qualified personnel?

ORGANIZATIONAL PROCESS: the organization must ensure that relevant standards have been established, qualified personnel have been trained to and assessed against those standards, and have maintained their currency.

MISSION: the mission exceeds the capability of the organization.

OVERSIGHT: were systemic deficiencies in selection, training, tasking and authorization procedures known and was corrective action taken?

If the answer to the question "…did the operator or crew had the pre-requisite capability, knowledge or skills required to sense and perceive the situation?" is YES, then there has been a breakdown in situation assessment.

Was the perceived **TIME PRESSURE** (*How much time you think it will take you to process all the information* divided by *The amount of time that you think is available before you have to action the decision*) excessive (more than 100% although people usually start to have problems above 80%)? Ask yourself "…if there had seemed to be more time available, would the outcome have been different?"

If the answer is NO then time pressure was NOT a factor and the failure has been **PERCEPTUAL,ATTENTIONAL** or in human-human or human-machine **COMMUNICATION**.

Was the **INFORMATION**: illusory or ambiguous?

If the answer is YES then the failure is **PERCEPTUAL**.

3.3.1 PERCEPTUAL FAILURE: The information was available but could be interpreted more than one way. There was a failure in **PERCEPTION.** In other words, all relevant sources of information were attended to, but an incorrect perception was formed due to illusory or ambiguous information.

PRE-CONDITIONS for a failure in **PERCEPTION**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

PSYCHOLOGICAL: the perceptual system can be fooled by illusory information (visual, aural, other) including those inputs that lead to spatial disorientation.

PHYSIOLOGICAL: vehicle motion can set the fluids of semi-circular canals in motion. This can generate incorrect perceptions of spatial orientation.

TRAINING: some of the more common illusory situations can be trained for. One can learn to suppress conflicting vestibular cues, strategies for the black hole effect, compensation for sloping runways or terrain effects on approach.

EQUIPMENT: Ambiguous displays of information (visual, auditory, other) can lead to misperceptions.

ENVIRONMENT: Poor lighting, glare or noisy environments can contribute to the ambiguity of the situation by making important information less detectable.

PERCEPTUAL INFORMATION PROCESSING BIASES: these biases shape how we weight the information we receive from the world (these are present in the absence of time pressure but become more dominant as time pressure increases). They are not *brain failures* but represent time efficient strategies for human problem solving. However, they can let us down due to the way they filter the available information. Here are some examples:

- Availability: the probability of an event occurring is evaluated by the ease with which relevant instances come to mind. In general, frequent events are easier to recall or imagine than infrequent ones and therefore .we think they are more likely to occur.
- Ignoring prior probabilities - ignoring the base rate or underlying probabilities of a particular situation (e.g., fog in the region at this time of year, excessive downdrafts with the wind from a particular quarter)
- Intuitive statistician: humans tend to overestimate the likelihood of occurrence of low probability events, and underestimate the occurrence of high probability events.
- Anchoring - the tendency for the order in which information is gathered to guide (or anchor) the interpretation of the situation. If the information is simple we tend to weight the information received first most heavily, if it is complex we tend to weight the most recently received information most heavily.
- As-if bias - people tend to weight all data as equally important to the decision process even if they are not.
- Representativeness heuristic – the tendency to assume that a situation that has similar characteristics to something you have experienced before, is indeed the same.
- Expectation – our perceptions are shaped by what we expect or do not expect (e.g., if you are cleared to land [expectation is that the runway is clear], you would not expect to see another aircraft occupying the runway).

MONITORING AND SUPERVISION: have inadequacies in equipment or environment been reported and has follow up action been initiated?

ORGANIZATIONAL PROCESS: is there a process for handing reports of hazardous or unsatisfactory equipment and environments?

ORGANIZATIONAL CLIMATE: are conditions that effect safe operations duly investigated and corrected?

OVERSIGHT: have systemic deficiencies in training, equipment or operating environment been recorded and has correcting action been taken?

Was the **INFORMATION**: available and correct? This means that there is a reasonable expectation that the information could be perceived correctly if attended to.

If the information is available and correct then the failure is **ATTENTIONAL**.

3.3.2 ATTENTIONAL FAILURE: If so, then the failure is to ATTEND to and assimilate relevant information that was present or accessible. This does not include situations where the information is displayed poorly (information illusory or ambiguous) or where critical cues are missing (information incorrect or missing).

PRE-CONDITIONS for a failure to **ATTEND**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

PHYSIOLOGICAL: fatigue, drowsiness.

PSYCHOLOGICAL: various psychological factors can contribute to attentional failures. For example: vigilance decrement, distraction, failure to use all available resources due to lack of motivation, or complacency. Distraction and Life Stress: factors external to the primary task that compete for attention (prolonged extraneous conversation, financial concerns, domestic problems, forthcoming exams or a meeting, a purchase etc.). While your attention is turned to these external events it is not available to apply to the primary task. These are pervading factors that act over extended periods of time during the performance of the task. They are not momentary distracters due to an alarm, a loud noise, or a brief flash in the visual field. Mental fatigue: weariness felt after long periods of intense mental activity and sustained attention that affects the ability to concentrate on the task at hand.

INFORMATION PROCESSING BIASES: Attentional information processing biases shape what we attend to (they are present in the absence of time pressure but become more dominant as time pressure increases). They are not *brain failures* but represent time efficient strategies for human problem solving. However, they can let us down as they filter the available information. Here are some examples:

- Salience - we are hard wired to attend to and place higher emphasis on information associated with loud sounds, bright lights, motion and position in our visual fields (in our central field, at the top of displays etc.). Highly salient cues can direct attention away from more important information.
- Confirmation bias - the tendency to seek out information that confirms our initial assessment rather than information that is contrary.

SOCIAL: peer pressure may make people extend the recommendations of established work-rest schedules. A lack of cohesiveness in a team can lead to reduced motivation and social loafing with reduced information seeking behaviour. Over confidence within the team may result in complacency with a resultant restriction in the locus of attention.

PERSONAL READINESS: leaving life stresses behind (these are distracters that consume attentional resources), reporting to work well rested.

TIME PRESSURE: sustained operation in a situation of excessive time pressure leads to chronic fatigue. Alternatively, the use of human operators in tasks that require sustained vigilance for long periods of time (more than 20-30 minutes at a time) will result in predictable decrements in performance.

EQUIPMENT: badly placed displays may reduce the likelihood that they will be attended to…they are outside the normal scanning pattern.

ENVIRONMENT: high noise or high vibration environments contributes to operator fatigue.

MONITORING AND SUPERVISION: was chronic fatigue detected amongst operators and was this information passed up the chain.

ORGANIZATIONAL PROCESSES AND PRACTICES: are there processes in place for monitoring the state of the operators and correcting the task objectives if necessary? Are scheduling guidelines in place that account for known human capabilities and limitations?

PROVISION OF RESOURCES: are sufficient personnel resources available to allow appropriate work-rest schedules?

ORGANIZATIONAL CLIMATE: are work-rest schedules respected or are people expected to put in the extra effort?

OVERSIGHT: were systemic problems with operator fatigue known and was corrective action taken?

Was the **INFORMATION**: unavailable or incorrect? This means that it could not reasonably be expected that the information could be correctly obtained and assimilated even if due attention was paid. It is not that the information is ambiguous, but rather that it is absent.

In this case the failure is in **COMMUNICATION**.

3.3.3 COMMUNICATION FAILURE: In this case the failure is in COMMUNICATION: between machine and human, or human and human including a failure to pass relevant information, or passing incorrect information.

PRE-CONDITIONS for a failure in **COMMUNICATION**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

PSYCHOLOGICAL: Human team members may have incorrect perceptions of a situation, or may retrieve the wrong information from memory. This can result in the incorrect information being passed to the person or persons involved in committing the unsafe act.

SOCIAL: certain factors will influence the willingness of team members to communicate freely and openly. For example: their commitment to the team, the level of trust and respect, and the authority gradient will affect their receptiveness to receive information (calibrate their mental models) and their willingness to communicate information.

EQUIPMENT: human-machine communication will be degraded by inadequate displays of information (lacking necessary cues) or displays that provide incorrect information.

ENVIRONMENT: Poor lighting, glare or noisy environments can mask information and prevent it from being communicated.

MONITORING AND SUPERVISION: have inadequacies in team working, equipment or environment been reported and has follow up action been initiated?

ORGANIZATIONAL PROCESS: is there a process for handing reports of hazardous or unsatisfactory team working, equipment and environments?

ORGANIZATIONAL CLIMATE: are conditions that effect safe operations duly investigated and corrected.

OVERSIGHT: were systemic problems in team working, equipment or environment known and corrective action taken.

If the answer to the question "…did the operator or crew had the pre-requisite capability, knowledge or skills required to sense and perceive the situation?" is YES, then there has been a breakdown in situation assessment.

Was the perceived **TIME PRESSURE** (*How much time you think it will take you to process all the information* divided by *The amount of time that you think is available before you have to action the decision*) excessive (more than 100% although people usually start to have problems above 80%)? Ask yourself "…if there had seemed to be more time available, would the outcome have been different?"

If the answer is YES then the perceived time pressure was excessive and there has been a breakdown in the time-attention trade-off. It is the time pressure at the point of failure — that is, at the time when the critical decision was processed — that is crucial although prolonged exposure to excessive time pressure can lead to chronic fatigue that can contribute to other failures. When the time pressure is excessive, the failure has either been **ATTENTIONAL** or in the use/non-use of **TIME MANAGEMENT** strategies.

3.4.1 ATTENTIONAL FAILURE: A failure in **ATTENTION** due to excessive demands in the time domain is a result of a breakdown in the time-attention trade-off. To know/perceive you must attend, and to attend you must have time.

PRE-CONDITIONS for a failure in **ATTENTION** due to excessive demands in the time domain: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

TIME PRESSURE: insufficient time to attend to all necessary information. The task uses too much of the timeline (>80%). Even with an effective time management strategy there would be insufficient time to attend to all the critical information.

PHYSIOLOGICAL: physiological conditions such as fatigue, effects of pharmacological and toxicological agents can slow information processing, increasing decision times and occupying the timeline. This will increase the time pressures experienced. If these factors were not operating, time pressure would have been acceptable.

PSYCHOLOGICAL: Mental fatigue: a weariness felt after long periods of intense mental activity and sustained attention that affects the ability to concentrate on the task at hand.

TRAINING: deficiencies in baseline knowledge mean that what should be fast skill-based problem solving becomes slower rule- or knowledge-based problem solving. Decisions take longer for the inadequately trained operator and time pressure increases accordingly.

EQUIPMENT: equipment that is difficult or awkward to use, or otherwise has a poor operator interface, can slow up the performance of the task to the point where the time pressure becomes elevated.

ENVIRONMENT: environmental variables such as glare, vibration, noise can increase the times required to assimilate information leading to increased time pressure.

MONITORING AND SUPERVISION: managers and supervisors need to be aware of tasks that impose excessive time pressures and initiate corrective action.

PROVISION OF RESOURCES: lack of resources, 'doing more with less', can lead to excessive tempos.

MISSION: inappropriate for the resources available.

OVERSIGHT: was it known that there were systemic problems with excessive time pressure at the task level, and was corrective action taken?

3.4.2 TIME MANAGEMENT FAILURE: A failure in TIME MANAGEMENT is due to an incorrect or inappropriate prioritisation of attention. Would a different sampling strategy have helped? There are essentially two strategies for managing excessive time pressure. One strategy is to make the task less difficult (meaning less information to process) by delegating, postponing, shedding activities or otherwise making the task less complex, a second strategy is to extend the time before you have to action the decision (slowing the task tempo). Did the operator or crew attempt to manage the timeline? Was the employed strategy effective and were there better strategies?

PRE-CONDITIONS for a failure in **TIME MANAGEMENT**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

TRAINING: part of the training process involves learning what is important and what can be ignored, and methods for controlling the tempo. An effective time management strategy depends on this knowledge.

TIME PRESSURE: task tempos that are inherently high generate high time pressures and routinely require the use of effective time management strategies.

MONITORING AND SUPERVISION: managers and supervisors need to be aware of tasks that impose excessive time pressures and ensure that training is appropriate.

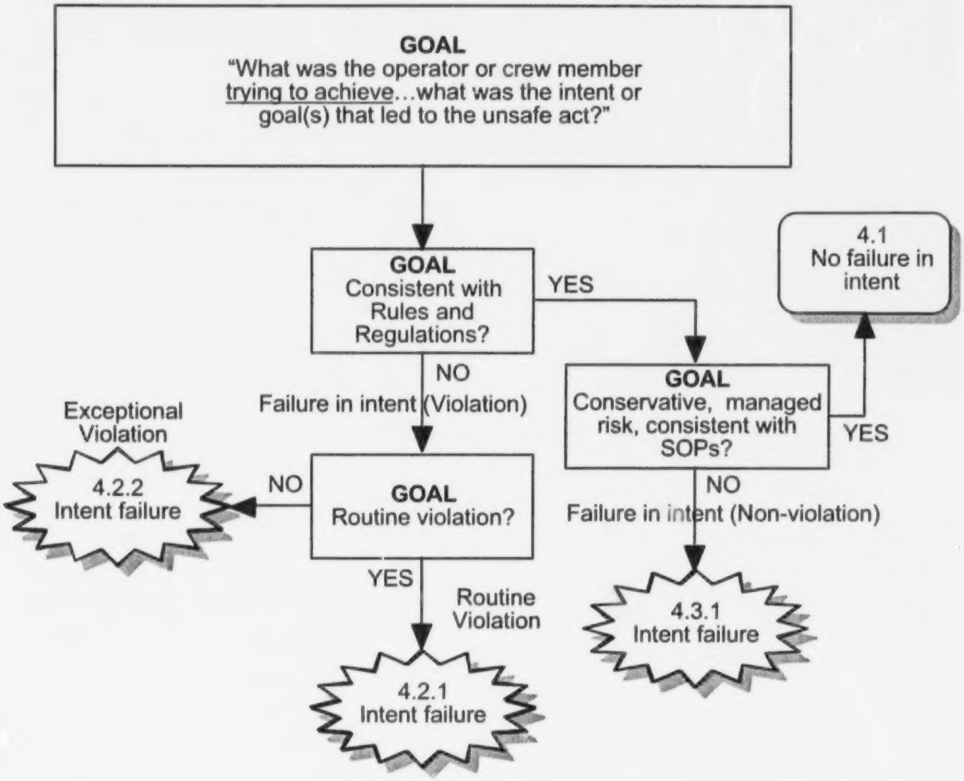
PROVISION OF RESOURCES: resources for training to the required level should be available.

MISSION: inappropriate for the resources available. The mission should be compatible with the current capabilities of all operators.

OVERSIGHT: were task temps routinely excessive, and was corrective action taken.

STEP 4 (What was the goal?)

Consider what the operator or crew was intending to do. What was the **GOAL**?


GOAL
"What was the operator or crew member trying to achieve...what was the intent or goal(s) that led to the unsafe act?"
GOAL Consistent with Rules and Regulations?
YES
4.1 No failure in intent
NO
Failure in intent (Violation)
Exceptional Violation
4.2.2 Intent failure
NO
GOAL Routine violation?
YES
Routine Violation
4.2.1 Intent failure
GOAL Conservative, managed risk, consistent with SOPs?
YES
NO
Failure in intent (Non-violation)
4.3.1 Intent failure

In the following text, the paragraph numbers match the numbers associated with each point of active failure.

Was the GOAL consistent with rules, regulations and SOPs, and was it also consistent with good risk management?

4.1 NO FAILURE IN INTENT: if the answer is YES, you would exit this branch with "no failure of intent" and move on to what the crew thought was happening (PERCEPTION) or what they were trying to do about it (ACTION).

But if the answer to any of these questions is NO, then there has been a failure in INTENT and you would need to look at the following possibilities.

The unsafe act resulted from exercising a goal that was inconsistent with Rules and Regulations. This is a failure of **INTENT (VIOLATION)**.

Was it a **ROUTINE VIOLATION** or an **EXCEPTIONAL VIOLATION**?

4.2.1 ROUTINE VIOLATION: A **ROUTINE VIOLATION** tends to be routine/habitual by nature and is a part of the individual's normal behaviour. This is often thought of as "bending" the rules. These violations are often tolerated and, in effect, sanctioned by supervisory authority. By definition, if a routine violation is identified, one must look further up the supervisory chain to identify those that are condoning the violations. Failures of Intent that result in violations do not require that the operator knowingly broke the rules.

PRE-CONDITIONS for a failure of **INTENT (ROUTINE VIOLATION)**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

TRAINING: lack of familiarity with the Rules and Regulations ("…I didn't know I was doing anything wrong")

PSYCHOLOGICAL: certain attitudinal states (e.g., anti-authoritarianism, group think) may result in personnel being more prone to tolerating routine violations.

SOCIAL: various social pressures (e.g., peer pressure, poor leadership) may contribute to routine rule breaking behaviour.

QUALIFICATION AND AUTHORIZATION: were the crew qualified and authorized to conduct the activity?

TIME PRESSURE: systemic excessive time pressure may cause operators to look for short cuts that get around the constraints of the Rules and Regulations.

OBJECTIVES: were the objectives for the task consistent with the communicated intent?

FORMING INTENT: was the intent of the activity clearly defined and in accordance with the organization's Rules and Regulations?

COMMUNICATING INTENT: was the intent of the activity clearly communicated and understood?

MONITORING AND SUPERVISION: somewhere the command and control/supervision chain has failed to detect and or correct systemic behaviours that deviate from the Rules and Regulations.

ORGANIZATIONAL CLIMATE the organization doesn't act in accordance with values based on safe operation, adherence to the rules etc. It doesn't reward those who try to keep these values, for example, the organization values and rewards 'getting the job done' above all else.

RULES AND REGULATIONS: rules and regulations form the constraints within which the task must be performed. Are they consistent with achieving the stated objectives?

OVERSIGHT: was rule breaking endemic, was this known, and was correcting action taken or was this behaviour condoned.

4.2.2 EXCEPTIONAL VIOLATION: Exceptional violations are isolated departures from authority and not necessarily typical of an individual's behaviour pattern. Usually,

management does not condone this behaviour. It is important to note that while most exceptional violations are flagrant, they are not considered 'exceptional' because of their extreme nature. Rather, they are considered exceptional because they are neither typical of the individual nor condoned by authority. Failures of Intent that result in violations do not require that the operator knowingly broke the rules.

PRE-CONDITIONS for a failure in **INTENT (EXCEPTIONAL VIOLATION)**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

TRAINING: lack of familiarity with the Rules and Regulations ("…I didn't know I was doing anything wrong").

PSYCHOLOGICAL STATES: certain attitudinal states (e.g., excessive motivation to achieve the task) may result in an operator being more prone to an exceptional violation.

INFORMATION PROCESSING BIASES: limit the information attended to, how it is perceived and the actions that come from the decision making process. The intent may not have been evaluated for potential violations.

SOCIAL: various social pressures (e.g., trans-cockpit or rank gradient, peer pressure, poor leadership) may contribute to rule breaking behaviour.

QUALIFICATION AND AUTHORIZATION: were the crew qualified and authorized to conduct the activity?

TIME PRESSURE: excessive time pressure may cause operators to look for short cuts that get around the constraints of the Rules and Regulations.

OBJECTIVES: were the objectives for the task consistent with the communicated intent?

FORMING INTENT: was the intent of the activity clearly defined and in accordance with the organization's Rules and Regulations?

COMMUNICATING INTENT: was the intent of the activity clearly communicated and understood?

MONITORING AND SUPERVISION: supervision should ensure that the team is qualified and authorised to perform the task and has planned an activity in accordance with the Rules and Regulations.

RULES AND REGULATIONS: rules and regulations form the constraints within which the task must be performed. Are they consistent with achieving the stated objectives?

Did the unsafe act result from exercising a goal that, although consistent with Rules and Regulations, was not consistent with established operating procedures or did not manage or bound the risk (the observed unsafe behaviour stemmed from a risky rather than conservative goal)?

If so, there was a failure in **INTENT (NON VIOLATION)**.

4.3.1 INTENT (NON-VIOLATION) FAILURE: For a goal to be classified as a failure of **INTENT (NON VIOLATION)**, the perception of the situation must be correct and you have to

intentionally choose the risky option (you may or may not have fully evaluated the risk). If there is no conservative option that will satisfy the task objectives, one would need to look to the task objectives and the mission requirements for the pre-conditions that have created this situation.

PRE-CONDITIONS for a failure of **INTENT (NON VIOLATION)**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

PSYCHOLOGICAL: certain attitudinal states (e.g., excessive motivation to achieve the task, overconfidence) may result in an operator being more prone to choosing risky behaviour and less prone to fully evaluating the risk.

INFORMATION PROCESSING BIASES: limit the information attended to, how it is perceived and the actions that come from the decision making process. The goal choice may not have been evaluated for risk. More conservative goals may not have been formulated for comparison with the chosen course.

TRAINING: There was a lack of familiarity with safe practices and risk management strategies.

QUALIFICATION AND AUTHORIZATION: were the crew qualified and authorized to conduct the activity?

OBJECTIVES: do the objectives of the task inherently involve high risk?

FORMING INTENT: was the intent of the activity clearly defined at the Command, Control and Supervisory level and did it balance risk against benefit?

COMMUNICATING INTENT: was the intent of the activity clearly communicated at the Command, Control and Supervisory level and understood?

MONITORING AND SUPERVISION: supervision should ensure that the team is qualified and authorised to perform the task and has planned an activity in accordance with safe practices and appropriate risk management criteria.

MISSION: the mission exceeds the capability of the organization.

RULES AND REGULATIONS: do the Rules and Regulations adequately manage foreseeable risk?

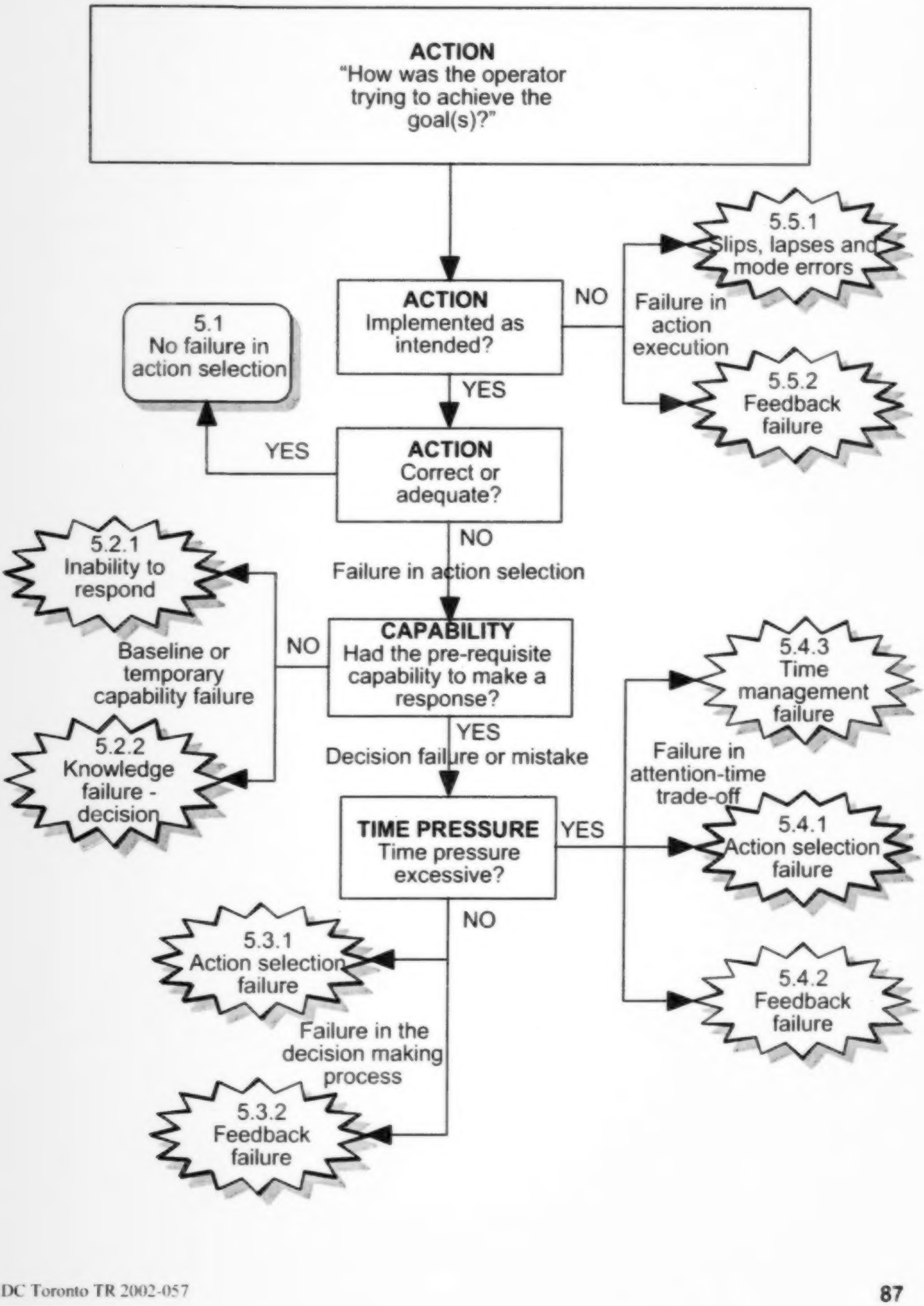
ORGANIZATIONAL PROCESS AND PRACTICES: does the organization have SOPs and formal risk management processes in place?

ORGANIZATIONAL CLIMATE: does the organization tolerate high risk as a matter of course?

OVERSIGHT: was it known that established risk management procedures were not being used routinely, and was corrective action taken?

STEP 5 (What was the action?)

Consider how the operator or crew was trying to achieve the Goal. What was the **ACTION**?


ACTION
"How was the operator trying to achieve the goal(s)?"
5.5.1
Slips, lapses and mode errors
ACTION
Implemented as intended?
NO
Failure in action execution
5.1
No failure in action selection
YES
5.5.2
Feedback failure
YES
ACTION
Correct or adequate?
NO
5.2.1
Inability to respond
Failure in action selection
CAPABILITY
Had the pre-requisite capability to make a response?
NO
Baseline or temporary capability failure
5.2.2
Knowledge failure - decision
5.4.3
Time management failure
YES
Decision failure or mistake
Failure in attention-time trade-off
TIME PRESSURE
Time pressure excessive?
YES
5.4.1
Action selection failure
NO
5.3.1
Action selection failure
Failure in the decision making process
5.4.2
Feedback failure
5.3.2
Feedback failure

In the following text, the paragraph numbers match the numbers associated with each point of active failure.

Was the action (including an intended no action), correct and adequate to achieve the goal in an appropriate (i.e., converging on the GOAL) and/or timely fashion?

5.1 No Failure in Action: If the answer is YES, then you would exit this branch with "no failure of action" and move on to what the crew thought was happening (PERCEPTION) or what they were trying to achieve (GOAL).

But if the answer to any of these questions is NO, then there has been a failure in **ACTION** selection or execution.

Now ask if the action that occurred was the intended action or not. Their action may not have had the intended results, but did they do what they intended to do?

Suppose the crew implemented the intended action to the perceived situation (including no action if this was the intended response), but the action selected (including an intended no action) was incorrect, was inadequate for achieving the goal in an appropriate and/or timely fashion, or the selected action didn't manage risk.

Did the operator or crew have the pre-requisite capability, knowledge or skills required to form and implement an appropriate action to the situation?

If the answer is NO then the failure must be either in the **KNOWLEDGE - DECISION** required to form the response or in the capabilities required to **RESPOND** to the situation (i.e., to implement the action).

5.2.1 RESPONSE FAILURE: A failure in the capability to **RESPOND** is a failure in the capability to implement the action rather than in not knowing what to do.

PRE-CONDITIONS for a failure to **RESPOND**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

PHYSICAL CAPABILITY: the crew or crewmember either permanently or temporarily lacked the physical capability to implement the action. Insufficient strength or endurance may make an operator temporarily or permanently unable to implement the required actions.

SELECTION: the selection system failed to screen out personnel lacking the basic physical capabilities (strength, reach, vocalization effort, etc.) that would allow the action to be implemented.

PHYSIOLOGICAL: physical injury or other physiological factors (e.g., cold exposure, heat stress).

PERSONAL READINESS: certain personal readiness factors may contribute to an inability to implement the action (e.g., muscle strains or injuries obtained outside the work environment, not having required protective equipment on hand).

QUALIFICATION AND AUTHORIZATION: were the crew qualified and authorized to conduct the activity?

OBJECTIVES: are the task objectives consistent with the physical capabilities of personnel who are expected to carry out the activities, or the performance of the equipment provided for the task?

EQUIPMENT: poor design or a failure in the equipment (e.g., power assistance) makes the action impossible for some or all qualified operators. Various items of personal equipment may interfere with the ability to implement the response (gloves, masks, harnesses etc.).

WORKSPACE: constraints within the workspace may make the required response difficult or impossible for certain members of the population, for example, physical obstructions, cramped working conditions.

ENVIRONMENT: certain environmental factors such as noise, g-loading, temperature, or vibration may make it difficult or impossible to implement the action.

MONITORING AND SUPERVISION: in authorising an activity, supervisors have a responsibility to ensure that operators are qualified and are capable of doing the job.

ORGANIZATIONAL PROCESS: the organization must ensure that relevant standards have been established, and that qualified personnel have been selected against those standards.

PROVISION OF RESOURCES: were adequate materiel and human resources available?

OVERSIGHT: were systemic deficiencies in selection standards known and was corrective action taken?

5.2.2 KNOWLEDGE (DECISION) FAILURE: A failure in KNOWLEDGE – DECISION is a failure in knowing how to respond appropriately and in a timely fashion, rather than having the capability to implement the action.

PRE-CONDITIONS for a failure in **KNOWLEDGE (DECISION)**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

SELECTION: the selection system failed to screen out personnel lacking the basic abilities (aptitude, problem solving abilities, etc.) that would allow an action to be formed.

TRAINING: the crew or crewmember had the basic abilities but lacked the task specific knowledge required to form an action.

CURRENCY: skills have degraded over time and have not been refreshed.

QUALIFICATION AND AUTHORIZATION: were the crew qualified and authorized to conduct the activity?

MONITORING AND SUPERVISION: in authorising an activity, supervisors have a responsibility to ensure that operators are qualified and current.

ORGANIZATIONAL PROCESS: the organization must ensure that relevant standards have been established, qualified personnel have been trained to and assessed against those standards, and have maintained their currency.

MISSION: the mission exceeds the capability of the organization.

OVERSIGHT: were systemic deficiencies in selection, training, tasking and authorization procedures known and was corrective action taken?

Suppose the crew implemented the intended action to the perceived situation (including no action if this was the intended response), but the action selected (including an intended no action) was incorrect, was inadequate for achieving the goal in an appropriate and/or timely fashion, or the selected action didn't manage risk.

Did the operator or crew have the pre-requisite capability, knowledge or skills required to form and implement an appropriate action to the situation? If the answer is YES then was the Time Pressure within limits?

Was the perceived **TIME PRESSURE** (*How much time you think it will take you to process all the information* divided by *The amount of time that you think is available before you have to action the decision*) excessive (more than 100% although people usually start to have problems above 80%)? Ask yourself "…if there had seemed to be more time available, would the outcome have been different?"

If the answer is NO then time pressure was not a factor and the failure has been in Action selection, or in the lack of Feedback.

5.3.1 ACTION SELECTION FAILURE: A failure in **ACTION SELECTION** is a failure in the decision process due to shortcomings in action selection, rather than a misunderstanding/misperception of the situation. These are failures to formulate the right plan rather than a failure to carry out the plan. For example:

- An incorrect or inadequate procedure was implemented as intended. A correct or adequate action does exist in memory but was not selected. This includes an inappropriate 'no action.' For example:
- Failures in knowledge-based reasoning due to working memory limitations, or processing biases.
- Failures in rule-based (IF 'A' then 'B') reasoning where once the IF part of the situation is recognised the THEN part of a previously used rule is inappropriately applied. This typically occurs when exceptions to rules are not recognised.
- Failures to use the appropriate technique, but only if the operator could demonstrate a correct or adequate technique under other circumstances.

PRE-CONDITIONS for a failure in **ACTION SELECTION**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

PSYCHOLOGICAL: limits in working memory capabilities limit our ability to manipulate large amounts of information in our head. This can lead to failures in problem solving at the rule and knowledge based levels.

DECISION BIASES: a failure in the decision process due shortcomings in action selection. These biases effect action selection (they are present in the absence of time pressure but become more dominant as time pressure increases). They are not *brain failures* but represent time efficient strategies for human problem solving. However, they can let us down due to filtering the available information. Here are some examples:

- Availability – the tendency to use the response that is most familiar or has been used recently.
- Over confidence – people in general are more confident of their chosen course of action than is reasonable given the uncertainty in the decision-making environment. There is the potential to close off the search for answers before all available evidence can be collected because of overconfidence.
- First-to-fit: the selection of the first course of action that seems appropriate. Operators often do not explore a complete or even a large set of options.
- Sunk cost bias – a tendency to put more resources into a process that you already have an investment in.
- Strategy persistence – a tendency to keep doing what you have been doing even though an outside observer can see that it is no longer appropriate (pressing on).

5.3.2 FEEDBACK FAILURE: If FEEDBACK is not present, such as when attention is shifted prematurely (before goal achievement), there is a failure in error correction. These include failures to backup, crosscheck or monitor to ensure that the goal has been achieved.

PRE-CONDITIONS for a failure in **FEEDBACK**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

PHYSIOLOGICAL: fatigue may result in a loss of vigilance.

PSYCHOLOGICAL: vigilance decrement may result in attention shifting before the results of an action can be observed.

SOCIAL: the authority gradient and variables such as assertiveness and receptiveness influence the extent to which feedback is offered and used for error correction within the team.

EQUIPMENT: controls and displays must give feedback to show the system state.

MONITORING AND SUPERVISION: the role of monitoring and supervision is to provide error-correcting feedback. When monitoring and supervision break down, there is no error correction at these levels.

Suppose the crew implement the intended action to the perceived situation (including no action if this was the intended response), but the action selected (including an intended no action) was incorrect, was inadequate to achieve the goal in an appropriate and/or timely fashion, or the selected response didn't manage risk.

Did the operator or crew have the pre-requisite capability, knowledge or skills required to form and implement an appropriate action to the situation? If the answer is YES then was the Time Pressure within limits?

Was the perceived **TIME PRESSURE** (*How much time you think it will take you to process all the information* divided by *The amount of time that you think is available before you have to action the decision*) excessive (more than 100%, usually people start to have problems above 80%)? Ask yourself "...if there had seemed to be more time available, would the outcome have been different?"

If the answer is YES then time pressure was a factor and the failure has been in **ACTION SELECTION**, in the lack of **FEEDBACK** or in the **TIME MANAGEMENT** strategy. This is a failure in the time-attention trade-off.

5.4.1 ACTION SELECTION FAILURE: A failure in **ACTION SELECTION** is a failure in the decision process due to shortcomings in action selection, rather than a misunderstanding/misperception of the situation. These are failures to formulate the right plan rather than a failure to carry out the plan. There is insufficient time to choose a correct or adequate course of action from memory even though it does exist or would likely be derived if more time were available. There is no time to generate alternatives and test them mentally for their appropriateness.

PRE-CONDITIONS for a failure in **ACTION SELECTION** under excessive time pressure: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

TIME PRESSURE: The tempo of the task is excessive. There is little or no time to rest or re-group, "...there is no time to think." Operators are paced by the task and have little scope to manage the timeline.

MONITORING AND SUPERVISION: managers and supervisors need to be aware of tasks that impose excessive time pressures and initiate corrective action.

PROVISION OF RESOURCES: lack of resources, 'doing more with less', can lead to excessive tempos.

MISSION: inappropriate for the resources available. The mission should be compatible with the current capabilities of the operator's.

OVERSIGHT: was it known that there were systemic problems with excessive time pressure at the task level, and was corrective action taken?

5.4.2 FEEDBACK FAILURE: If **FEEDBACK** is not present, such as when attention is shifted prematurely (before goal achievement), there is a failure in error correction. These are failures to backup, crosscheck or monitor to ensure that the goal has been achieved. There is no time to close the loop.

PRE-CONDITIONS for a failure in **FEEDBACK** under excessive time pressure: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

TIME PRESSURE: The tempo of the task is excessive. There is little or no time to rest or re-group, "…there is no time to think." Operators are paced by the task and have little scope to manage the timeline.

MONITORING AND SUPERVISION: managers and supervisors need to be aware of tasks that impose excessive time pressures and initiate corrective action.

PROVISION OF RESOURCES: lack of resources, 'doing more with less', can lead to excessive tempos.

MISSION: inappropriate for the resources available. The mission should be compatible with the current capabilities of the operator's.

OVERSIGHT: was it known that there were systemic problems with excessive time pressure at the task level, and was corrective action taken?

5.4.3 TIME MANAGEMENT FAILURE: A failure in TIME MANAGEMENT results from an incorrect or inappropriate prioritisation of attention. Would a different sampling strategy have helped? There are essentially two strategies for managing time pressure, one can make the task less difficult (meaning less information to process) by delegating, postponing, shedding activities or otherwise making the task less complex, or by extending the timeline before you have to action the decision (slowing the task tempo).

PRE-CONDITIONS a failure in **TIME MANAGEMENT**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present.

TRAINING: part of the training process involves learning what is important and what can be ignored and methods for controlling the tempo. An effective time management strategy depends on this knowledge.

TIME PRESSURE: task tempos that are inherently high generate high time pressures and require the use of effective time management strategies.

MONITORING AND SUPERVISION: managers and supervisors need to be aware of tasks that impose excessive time pressures and initiate corrective action.

PROVISION OF RESOURCES: lack of resources, 'doing more with less', can lead to excessive tempos.

MISSION: inappropriate for the resources available. The mission should be compatible with the current capabilities of the operator's.

OVERSIGHT: was it known that there were systemic problems with excessive time pressure at the task level, and was corrective action taken?

Suppose the crew's actual action was not the intended or planned response. These are the real errors. Given the same circumstances they may not occur again in the same form. Of all the categories they are the most random and the most difficult to defeat. The failure is in the commission of a **SLIP, MISS OR LAPSE** and/or in dropping **FEEDBACK**.

5.5.1 SLIPS, MISSES AND LAPSES: In all cases of **SLIPS, MISSES AND LAPSES,** the intended action was not implemented. This is a failure in action execution rather than action selection.

What was done was not what was intended. The wrong sequence or plan was triggered. For example:

- Slips, misses and bungles: occur when the intended behaviour is 'captured' by a similar well-practised behaviour (e.g., operating the gear lever instead of the flap lever). These are failures in skill-based behaviour. Slips may occur when: the intended action involves a slight departure from the routine; some characteristics of the stimulus of the action sequence are related to the inappropriate but more frequent action; the action is relatively automated (skill-based behaviour) and is therefore not closely monitored (feedback).
- Lapses: a planned response was not actioned at the appropriate time, missed a check list item or a step in a procedure, left a tool in the work area, torquing a nut at the end of an assembly procedure, bumping into something or inadvertently activating a control. Lapses are what might be called forgetfulness, often precipitated by an interruption. Lapses are often seen in maintenance and installation procedures.
- Mode errors: performing an action that is inappropriate in the current mode but would be appropriate in another mode. Generally these errors occur when the operator forgets which mode is selected or forgets that the action they are about to perform gives different than expected results in the current mode.

PRE-CONDITIONS for **SLIPS, MISSES AND LAPSES**: some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present. These are points of intervention for reducing the likelihood that the slip, miss or bungle will occur in the first place.

TRAINING: many mode errors can be traced to an incomplete understanding (mental model) of system function.

EQUIPMENT: poor equipment design can result set the scene for the propagation of these errors. For Example, proximity of flap and gear handles, similar look and feel to controls, layout different to the conventional arrangement.

ORGANIZATIONAL PROCESS AND PRACTICES: Procedures can assist in preventing failures due to memory limitations (shadow boards for tools, independent sign-offs, challenge-response methods, noting the last step performed when interrupted, etc.). Are there Standard Operating Procedures for trapping these types of errors?

RULES, REGULATIONS: are there Rules and Regulations for trapping these types of errors? For example the existence and use of mandated checklists.

OVERSIGHT: was it known that there were a high number of these types of incidents, and was corrective action taken?

5.5.2 FEEDBACK FAILURE: When **FEEDBACK** is not present, such as when attention is shifted prematurely (before goal achievement), there is a failure in error correction. These are failures to backup, crosscheck or monitor to ensure that the goal has been achieved. Feedback can catch unintended responses such as slips, misses, bungles and mode errors, as the deviation from intended action is often easily detected. In the supervisory role, feedback may counteract lapses.

PRE-CONDITIONS for a failure to **TRAP** Slips, Misses and Lapses: This is a failure in **FEEDBACK**. Some or all of the following pre-conditions (latent factors both immediate and remote) may or may not be present. Factors other than those following may also be present. These are points of intervention for recovering from the slip, miss or bungle after it has occurred.

> **TIME PRESSURE**: task tempos that are inherently high generate high time pressures and require the use of effective time management strategies to ensure that feedback is not dropped for critical loops.
>
> **SOCIAL**: a strained team environment is likely to reduce the willingness of team members to backup and provide error-correcting feedback.
>
> **ENVIRONMENT**: poor lighting, glare, vibration or noise can reduce cues that would facilitate the trapping of these errors.
>
> **MONITORING AND SUPERVISION**: managers and supervisors need to be aware of tasks that impose excessive time pressures and initiate corrective action. Monitoring and supervision provides error-correcting feedback to ensure that error traps are in place.
>
> **PROVISION OF RESOURCES**: lack of resources, 'doing more with less', can lead to excessive tempos.
>
> **MISSION**: inappropriate for the resources available. The mission should be compatible with the current capabilities of the operators.
>
> **OVERSIGHT**: was it known that there were systemic problems with excessive time pressure at the task level, or that there was an excess of these types of incidents, and was corrective action taken?

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Annex C: An example of a SERA Analysis

The following example was taken from the National Transportation Safety Board's data base (http://www.ntsb.gov/NTSB/query.asp)

NTSB Identification: LAX01LA065

Accident occurred Tuesday, December 26, 2000 at COLORADO CITY, AZ

Aircraft: Cessna T210N, registration: N4729C

Injuries: 4 Minor.

On December 26, 2000, about 1645 hours mountain standard time, a Cessna T210N, N4729C, was substantially damaged during an off-airport forced landing at Colorado City, Arizona. The forced landing was precipitated by a loss of engine power during initial climb. The airline transport pilot and three passengers received minor injuries. Visual meteorological conditions prevailed for the personal flight operating under 14 CFR Part 91, and no flight plan was filed. The personal flight was originating at Colorado City as a local area personal scenic flight.

The pilot, who is also a maintenance technician, had just completed an annual inspection and installed an overhauled engine in the airplane. The pilot stated that he had flown the airplane three times for a total of about 2.5 hours.

During takeoff and initial climb, about 400 to 500 feet agl, the engine lost power. The pilot activated the fuel hi-boost pump, which generated brief surges of engine power. He performed a 180-degree turn back towards the airport, but was unable to reach the runway and collided with rocky terrain.

The pilot stated that he visually checked both fuel tanks during the preflight, observing about 1 inch in the left tank and about 1.5 inches in the right tank. He then checked the fuel gages, which showed about half full for each tank. At the time of the accident the fuel selector was on the left tank. The pilot stated that during a postaccident examination he found the left tank was empty. He also reported that after recovering the airplane and applying electrical power the left fuel gauge was stuck at 3/8 full.

The following is a slightly edited version of the report generated by the SERA v1.0 application. Edits are small and relate mainly to the order in which information is presented. It is intended that v1.1 of the application will produce output that closely follows this format.

Report Title: NTSB Identification: LAX01LA065

Report Date: Apr. 15, 2002

Report Time: 4:16 PM

Author: Keith Hendy

Affiliation: HSMG/SMART/DRDC Toronto

Incident Date: Tuesday, December 26, 2000

Incident Time: 1645 hours mountain standard time

Incident Description: The airline transport rated pilot, who is also a maintenance technician, had just completed an annual inspection and installed an overhauled engine in the airplane. He stated that he had flown the airplane three times for a total of about 2.5 hours. During takeoff and initial climb, about 400 to 500 feet agl, the engine lost power. The pilot activated the fuel hi-boost pump, which generated brief surges of engine power. He performed a 180-degree turn back towards the airport, but was unable to reach the runway and collided with rocky terrain. He stated that he visually checked both fuel tanks during the preflight, observing about 1 inch in the left tank and about 1.5 inches in the right tank. He then checked the fuel gages, which showed about half full for each tank. At the time of the accident the fuel selector was on the left tank. The pilot stated that during a postaccident examination he found the left tank was empty. He also reported that after recovering the airplane and applying electrical power the left fuel gauge was stuck at 3/8 full.

The unsafe act or unsafe condition that marks the first point in the timeline where there was a departure from safe operation was:

The pilot took off with less than the required fuel on board.

The operator or crewmember believed the state of the world with respect to the goal(s) was:

The pilot believed he had sufficient fuel to complete the flight.

Additional Remarks:

Although there is no evidence to show that the pilot conducted any fuel burn calculations he did visually check the fuel state of each tank and the gauges prior to take-off. The pilot observed about 1 inch of fuel in the left tank and 1.5 inch of fuel in the right tank. The fuel gauges showed about 1/2 full. It is possible that the aircraft had flown at least 2.5 hours since refuelling for 3 take offs and landings.

It is assumed that the pilot would not have conducted this flight unless he believed he had sufficient fuel on board.

The intent or goal(s) that led to the unsafe act was:

The pilot intended to conduct a local area scenic flight with passengers.

The operator or crewmember was trying to achieve the goal(s) by the following means:

The pilot intended to conduct a normal VFR flight.

PERCEPTION FAILURES

The crew's assessment of the situation did not match the actual situation.

Brief Description of Crew's Assessment:

The pilot's assessment of the fuel on board was incorrect.

The operator or crew had the pre-requisite capability, knowledge or skills required to sense and perceive the situation.

Brief Description of Crew's Capability:

The pilot was an ATP with maintenance technician qualifications. He had just completed an annual inspection and engine replacement on the aircraft. It can be assumed that he had some familiarity with the Cessna 210N and its systems.

The perceived TIME PRESSURE was not excessive.

Brief Description of Time Pressure:

There is no evidence of any excessive time pressure for what was a personal local area flight.

The information was illusory or ambiguous.

Brief Description of Information:

Information regarding the fuel load (visual tank inspection, fuel gauges, flight time since last refuelling) was ambiguous. The fuel gauges gave a crisp but incorrect indication of fuel load, while the imprecise visual inspection of the tanks did not key the pilot to the true fuel state.

Conclusion:

PERCEPTUAL FAILURE: The information was available but could be interpreted more than one way.

The AGA 135 HFACS equivalent terminology for this failure:

Active Failure: Perceptual

Additional Remarks:

Visual inspection of the fuel tanks should have provided a clue that fuel was insufficient for the flight, however the fuel gauges provided a false indication of approximately half tanks.

The information provided was contradictory and ambiguous. The resulting perception is likely to depend on the order in which the information was obtained and what information is weighted more heavily.

A third piece of information was available but appears not to have been factored into the equation. The aircraft may have flown at least 2.5 hours since refuelling. Total endurance of a Cessna 210N is approximately 3.5 hours if leaned for cruise flight.

Pre-conditions:

The following pre-conditions were answered "YES":

EQUIPMENT: Ambiguous displays of information (visual, auditory, other) can lead to misperceptions.

The AGA 135 HFACS equivalent terminology for the selected pre-conditions:

Pre-condition: Equipment

Additional Remarks:

One fuel gauge (the left) was obviously faulty and the other was perhaps optimistic. The gauges did not correctly represent the fuel state of the aircraft.

Fuel gauges in light aircraft are notoriously unreliable, yet in this case it appears they were believed over other sources of (conflicting) information. The gauges provide information in a direct and relatively easily understood fashion. A visual inspection requires considerably more complex information processing to turn what can be observed into a meaningful measure of flight time. This message needs to be re-enforced in the community again. A pilot should back up gauge indications with at least one other independent source of information.

PERCEPTUAL INFORMATION PROCESSING BIASES: these biases shape how we weight the information we receive from the world (these are present in the absence of time pressure but become more dominant as time pressure increases).

The AGA 135 HFACS equivalent terminology for the selected pre-conditions:

Pre-condition: Adverse mental states

Additional Remarks:

The order in which information was gathered may have affected the pilot's perception of fuel on board. The visual inspection should have given cause for concern, as 1-1.5in of fuel is possibly insufficient to ensure the pick up remains immersed. Gauging fuel contents from a visual inspection is imprecise but a gauge appears to give a crisp indication and seems to have been accepted as ground truth. Other information such as the flight time since last refuelling appeared to be ignored. All the information needed to accurately gauge the fuel state of the aircraft was available but it was not congruent.

GOAL FAILURES

The goal was not consistent with rules, regulations and SOPs.

Brief Description of Relevant Regulations:

The pilot took off with less than the amount of fuel required for this flight (flight time+45mins). It is assumed that this was not an intentional violation of the Rules.

It was not a routine violation.

Conclusion:

EXCEPTIONAL VIOLATION: Exceptional violations are isolated departures from authority and not necessarily typical of an individual's behaviour pattern.

The AGA 135 HFACS equivalent terminology for this failure:

Active Failure: Violation - exceptional

Additional Remarks:

There is no evidence to suggest that this pilot routinely violates the Rules and Regulations. It is assumed that the violation was not deliberate and that the pilot believed that the fuel state was sufficient for the trip planned.

Pre-conditions:

The following pre-conditions were answered "YES":

INFORMATION PROCESSING BIASES: limit the information attended to, how it is perceived and the actions that come from the decision making process.

The AGA 135 HFACS equivalent terminology for the selected pre-conditions:

Pre-condition: Adverse mental states

Additional Remarks:

The problem appears to be with the incomplete evaluation of the information available and the inability to resolve conflicting information.

ACTION FAILURES

The action that occurred was the intended action. Their action may not have had the intended results, but they did do what they intended to do.

The action (including an intended no action) was correct and adequate to achieve the goal in an appropriate (i.e., converging on the GOAL) and/or timely fashion.

Brief Description of Action Appropriateness:

The flight was proceeding as intended until the first signs of fuel starvation were detected.

Conclusion:

This conclusion is consistent with my understanding of the situation.

The AGA 135 HFACS equivalent terminology for this failure:

No failure

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List of symbols/abbreviations/acronyms/initialisms

AC	Aircraft Commander
AGL	Above Ground Level
C2	Command and Control
CF	Canadian Forces
DCIEM	Defence and Civil Institute of Environmental Medicine
DFS	Directorate of Flight Safety
DND	Department of National Defence
DRDC	Defence Research and Development Canada
FMS	Flight Management System
HFACS	Human Factors Accident Classification System
ILS	Instrument Landing System
IP	Information Processing
MDA	Minimum Descent Altitude
NTSB	National Transportation Safety Board
PCT	Perceptual Control Theory
SERA	Systematic Error and Risk Analysis
SMART	Simulation and Modelling for Acquisition, Rehearsal and Modelling
SOP	Standard Operating Procedure

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14. ABSTRACT

(U) A tool for Systematic Error and Risk Analysis (SERA), based on a solid theoretical framework provided by the Information Processing (IP) and Perceptual Control Theory (PCT) models, has been developed for investigating the human factors causes of accidents and incidents. SERA provides a structured process for identifying both active failures and the pre-conditions that led to these failures. In the context of this report, SERA is developed as a tool to help the accident investigator in populating the Canadian Forces version of the Human Factors Accident Classification System or HFACS. Yet SERA provides its own taxonomy of human factors causes and could stand alone, independent of HFACS, as both an investigation tool and as an accident classification taxonomy. Because of the strong separation between the active failures and pre-conditions that mark the points of intervention for the safety system, SERA can be extended to provide a risk management tool at both the tactical (for operators) and strategic (for managers) levels. A concept for a risk management tool is developed, based on 12 SERA factors at the tactical level and six SERA factors at the strategic level. The use of a software tool for implementing the steps of the SERA analysis is demonstrated.

(U) Un outil d'analyse systématique des erreurs et du risque (SERA) a été développé pour enquêter sur les facteurs humains en cause dans les accidents et les incidents. Il est fondé sur un cadre théorique solide élaboré à partir du modèle de traitement de l'information (TI) et de celui des principes du contrôle perceptif (PCP). La SERA offre un processus structuré permettant d'identifier à la fois les défaillances actives et les préconditions ayant mené à ces défaillances. Dans le contexte de ce rapport, la SERA a été développée en tant qu'outil pour aider les enquêteurs sur les accidents à charger le système d'analyse et de classification des facteurs humains (SACFH) propre aux Forces canadiennes. Pourtant, la SERA a sa propre taxonomie des causes de facteurs humains et pourrait opérer par elle-même, indépendamment du SACFH, comme un outil d'enquête et comme une taxonomie de classification des accidents. Vu le grand écart entre les défaillances actives et les préconditions amenant des interventions du système de secours, la SERA peut aussi servir d'outil de gestion du risque aux niveaux tactique (pour les utilisateurs) et stratégique (pour les gestionnaires). Un concept d'outil de gestion du risque est développé selon 12 facteurs SERA au niveau tactique, et selon 6 facteurs SERA au niveau stratégique. L'utilisation d'un outil logiciel pour mettre en oeuvre les étapes de la SERA est expliquée.

15. KEYWORDS, DESCRIPTORS or IDENTIFIERS

(U) SERA;Human Error Taxonomy;Accident Investigation;Risk Analysis; Perceptual Control Theory

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NORTH ATLANTIC TREATY ORGANISATION

RESEARCH AND TECHNOLOGY ORGANISATION
BP 25, 7 RUE ANCELLE, F-92201 NEUILLY-SUR-SEINE CEDEX, FRANCE

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Spatial Disorientation in Military Vehicles: Causes, Consequences and Cures

(Désorientation spatiale dans les véhicules militaires: causes, conséquences et remèdes)

Papers presented at the RTO Human Factors and Medicine Panel (HFM) Symposium held in La Coruña, Spain, 15-17 April 2002.

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